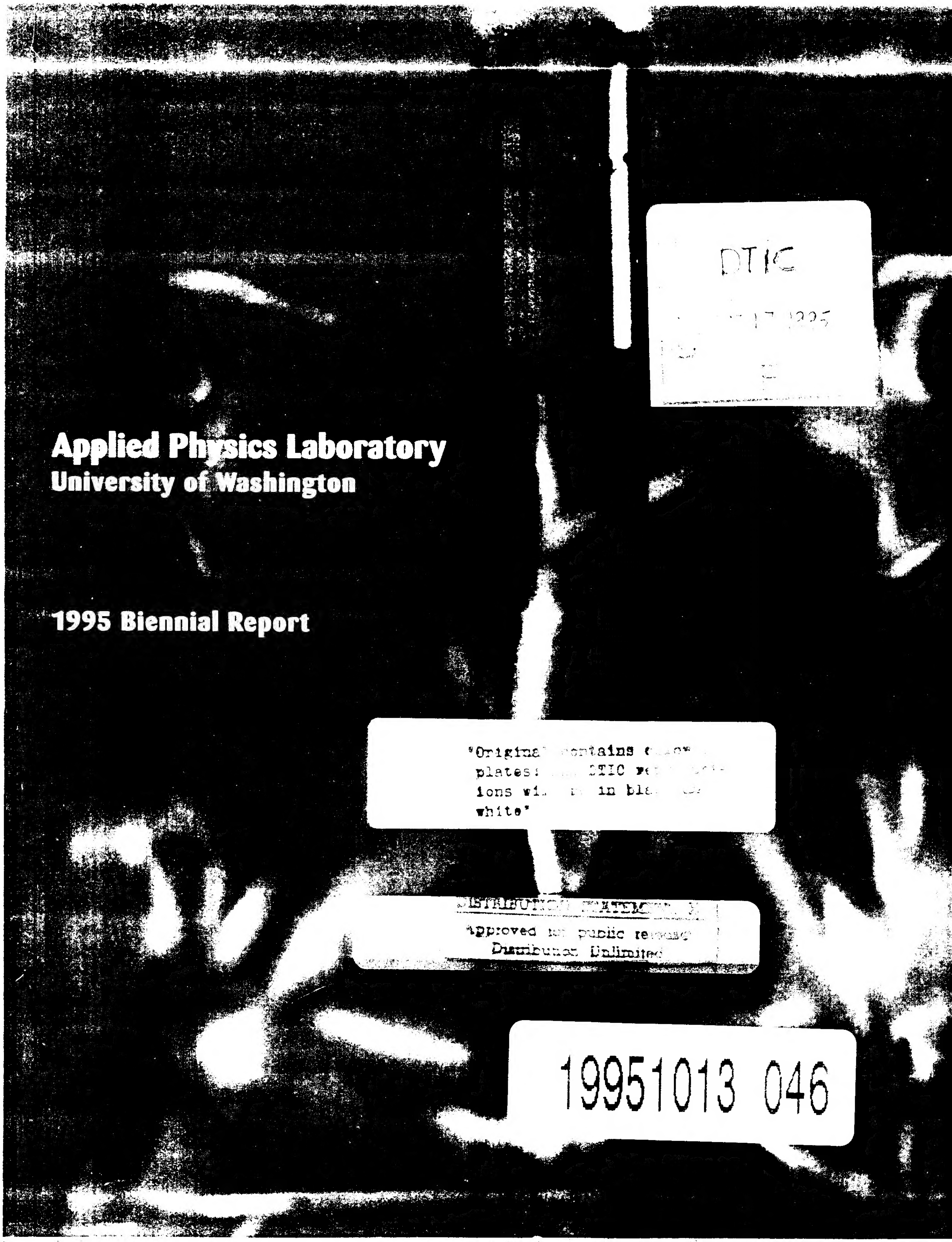

Applied Physics Laboratory
University of Washington

1995 Biennial Report

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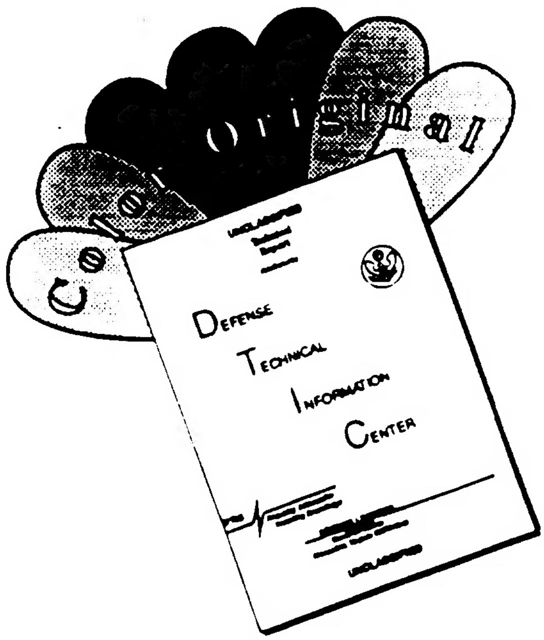

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Applied Physics Laboratory
College of Ocean & Fishery Sciences
University of Washington

1995 Biennial Report

Formed in 1943 in response to a Navy request for assistance in developing a torpedo influence exploder, the Applied Physics Laboratory (APL) of the University of Washington has evolved into a well-known and respected source of research and development in ocean science, ocean acoustics, and ocean engineering. The partnership with the Navy that began over 50 years ago continues today with a program based in fundamental research and grounded by expertise developed over years of working on Navy problems. Sponsorship is also drawn from other federal agencies, and APL staff collaborate closely with University faculty to provide innovative and imaginative solutions to complex technical problems. Basic research includes ocean physics, polar oceanography, remote sensing, and ocean acoustics, all of which draw upon the Laboratory's demonstrated expertise in designing and deploying specialized instrumentation. This fundamental research underpins and facilitates applications to real-world problems, which range from medical imaging to global warming to firefighter training. The articles selected for inclusion in this report give just a sampling of a program that, at any time, may comprise hundreds of individual projects.

A research unit of the College of Ocean and Fishery Sciences, the Laboratory is located in Henderson Hall on the campus of the University of Washington. Full-time staff number approximately 250, with 155 scientists and engineers. Currently, 26 hold faculty appointments and supervise graduate students.

The Laboratory is equipped with machine and electronics shops, a library, and drafting and publication facilities. Computing needs are addressed by a combination of special purpose machines, central facilities, and networked personal computers and workstations. Special laboratories are available for microwave remote sensing, image processing, transducer development and testing, electronic system development, and physical acoustics. The Laboratory operates two research vessels, including a self-propelled acoustic test facility, which operate from a marine facility on nearby Lake Union. Access to Puget Sound and deep water is available through a system of locks.

The Applied Physics Laboratory is funded entirely by grants and contracts, receiving approximately three-fourths of its support from Navy sponsors. Other major sources of funding include the National Science Foundation, the National Aeronautics and Space Administration, and the Advanced Research Projects Agency.

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Cover: Multiple-bubble sonoluminescence produced by an ultrasonic horn. See related article on page 10. Photo by Lawrence Crum.

From the Director

Robert C. Spindel

The changes that began five years ago with the end of the Cold War are upon us full force. The Department of Defense and the U.S. Navy are undergoing radical transformation to accommodate an entirely new defense environment. Forces and facilities are being reduced. Focus is shifting from the prevention of global nuclear war to an array of uncertain defense and national security issues—regional conflicts, terrorism, drug trafficking, the spread of nuclear weapons, international peacekeeping. At the same time there is an imperative to come to grips with an unbalanced national budget and a soaring national debt. Against this backdrop is a revolution in communication technology that has altered our personal lives and changed the conduct of military affairs.

The role of science and technology in this uncertain future is undergoing unprecedented public scrutiny and debate, and the role of laboratories such as APL is being examined. The mission of federal laboratories, the relationship between the Defense Department and universities, and the type of research to be sponsored by federal agencies are all being reviewed. What does the country need? What can we afford to do without? Where should our efforts be focused?

How does APL fit in?

We have worked with the Navy for more than fifty years to help make it the best in the world. Since 1943 we have operated continuously as a Navy-oriented research and development activity structured to address the needs of the naval warfare establishment. Our mission has been to conduct, within the broader mission of the University of Washington, a program of fundamental research, technological advancement, engineering, and education emphasizing Navy applications of ocean science and ocean engineering. Knowledge about the ocean is still critical to the Navy's operations, and we see no less need in an uncertain future. If anything, uncertainty about where the Navy will be forced to operate, what it will be required to do, which weapons it will need, and how it will be integrated into joint and coalition forces, makes the need greater.

Until recently, APL was an organization focused largely on weapon research and development—torpedoes in particular—and on operational requirements. APL developed the wire-guided torpedo, underwater acoustic test ranges, fleet readiness accuracy check sites, sonar training devices, and tracking ranges for under-ice submarine operations. While we will continue to be involved in these activities, Naval Warfare Centers and the private sector have become the main participants in system development. But they do not conduct the research that will provide the basis for solutions to tomorrow's challenging problems, nor do they easily bridge the gap between academe and the military. We do both. Our uniqueness lies in the position we hold; one foot in the university community, the other in the Navy. We are part of both cultures.

To meet the future we have deliberately evolved into a laboratory that capitalizes on this great strength. Our program today is dominated by basic research and the transition of research ideas to the Fleet. Fully 60% of our effort is devoted to fundamental investigations of the processes that govern the behavior of the oceans and the atmosphere, to the study of polar regions, to sound transmission in the sea, and to the physics of bubbles and ultrasound. The Office of Naval Research is our largest sponsor. We serve tomorrow's Navy as a bridge from university research to military product.

We offer a graduate education program that develops engineers and scientists who understand the ocean and the atmosphere and how the Navy operates in these environments. In the sense that information will be the coinage of the future, and Information Warfare will be the basis for military victory, bright, energetic, knowledgeable and committed people will help ensure that we remain the world's leading economic and military power.

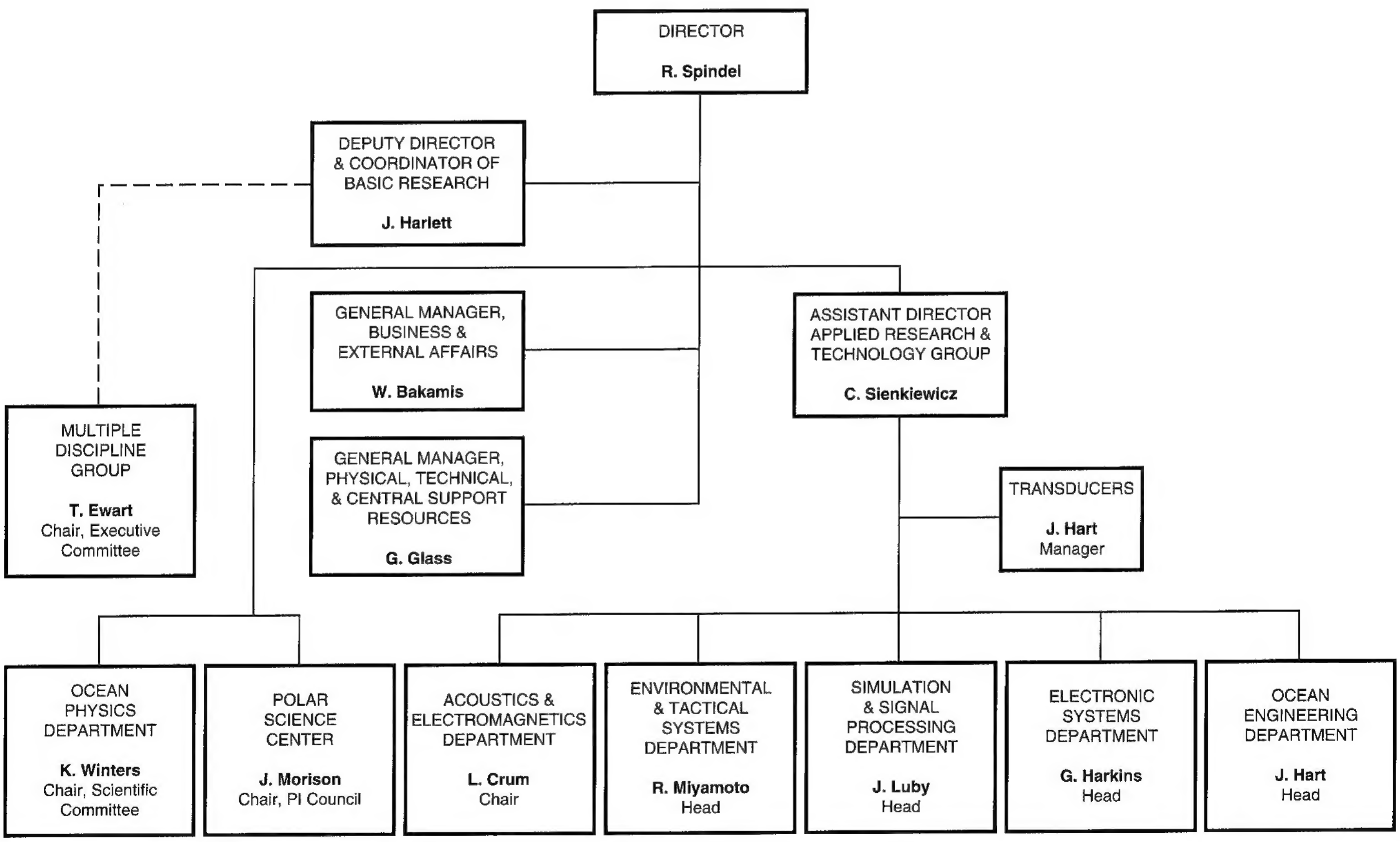
The articles in this report are a small sample of APL's total program, but their diversity illustrates the changes taking place. The articles on POLES and the Expedition to the North Pole describe fundamental studies of the combined ocean-atmosphere system with the goal of furthering our understanding of the complex relationships that drive the Earth's weather and climate. On the other hand, the DCLASP and Digital Environmental Guides articles illustrate how basic research is translated into a Navy product. In the former case, understanding the effects on underwater sound of ocean mixing processes and interaction with the surface and bottom allows one to improve sonar detection and classification in difficult shallow water regions. In the latter, scientific knowledge of the ocean environment is presented for operational use in an easily understood CD-ROM format. Similarly, the Diver Evaluation Unit (DEU), a device to help Explosive Ordnance Disposal teams improve skills, is a direct transition to the Fleet. Acoustic thermometry of the ocean serves a dual purpose. On one hand it is a new measurement technique that will provide much needed data on possible ocean

warming in order to test model predictions, and on the other, it is breaking new ground in understanding the limits of long-range sound propagation in the ocean, the principal method of submarine surveillance.

The articles on firefighter training and the CD-ROM for Puget Sound illustrate the trend towards adopting for civilian use technologies developed by the military. Both use the interactive CD-ROM environment that has been exploited for conveying complex environmental information to Navy tacticians. The work on medical ultrasonics and sonoluminescence had its origins in Navy research focused on the effects of cavitation bubbles on propeller design for optimum quieting and maximum strength.

APL has earned a reputation for successful field operations, often using equipment and techniques developed within the Laboratory. We will continue to rely on that strength in gathering data and testing hypotheses at sea and on the ice, as illustrated by the articles on the electric field float and IBEX/CABEX. They describe new instruments to measure the ocean. In a future where our dependence on computer simulation and model prediction will increase, it is vitally important that these tools incorporate a correct understanding of the underlying physical processes and that they be validated with field data.

APL is positioned to meet the challenges of global and national transformations and to continue to serve the Navy in the new defense environment. We have extended our range of activities, broadened our sponsorship, expanded our interdisciplinary efforts, and altered our mix of basic versus applied programs. Our solid base in fundamental science, enviable competency in engineering, and broad understanding of the Navy and its requirements will serve the needs of the future.



Polar Science

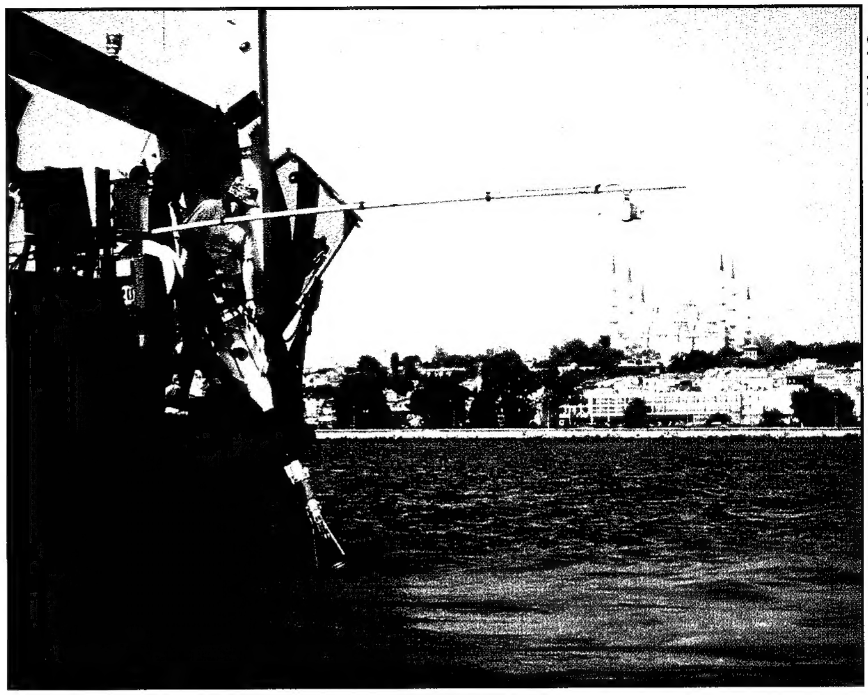
Research in the Polar Science Center (PSC) focuses on observing and modeling the physical processes that control the nature and distribution of sea ice, the structure and movement of high-latitude oceans, and the interactions between air, sea, and ice. The Center, which had its origins in the multiyear Arctic Ice Dynamics Joint Experiment (AIDJEX), a major program conducted during the 1970s, has become a leader in Arctic remote sensing, ice dynamics, polar oceanography, and polar logistics.

The relationship between polar regions and the global climate system is of particular interest. PSC scientists have taken major roles in international research programs involving process studies and large-scale observations, including the Marginal Ice Zone Experiments (MIZEX), the Coordinated Eastern Arctic Experiment (CEAREX), the Lead Experiment (LEADEX), and the U.S./Canadian Arctic Section. Staff are currently in leadership positions in the International Arctic Buoy Program, the Arctic Systems Science (ARCSS) program, and the World Climate Research Program.

The Center has developed a variety of instruments for collecting meteorological and oceanographic data in the polar regions. A small autonomous vehicle has obtained salinity and temperature data beneath the ice which show the horizontal structure of mixing on scales not measurable by conventional techniques. The Polar Ocean Profile buoy automatically measures ocean temperature and salinity, air temperature, and barometric pressure and transmits the data through a satellite link. Another instrument, the Freeze-In Buoy, is deployed in a crack (or lead) in the pack ice to capture the earliest stages of ice growth and heat exchange. The Upward Looking Sonar, attached to a bottom mooring, measures the draft of the ice above it. Several of these sonars are monitoring ice thickness in various regions of the Arctic.

Model development is focused on understanding and predicting the air–sea–ice system. Included are studies of mesoscale and large-scale ocean circulation kinematics, dynamics, and thermodynamics, statistical properties of sea ice, boundary-layer processes in the atmosphere and ocean, atmospheric radiation, ocean convection, and coupled system behavior. The modeling work—which uses newly acquired data for model initialization, forcing, and validation—contributes to understanding how the polar regions interact with world climate.

Satellite remote sensing techniques are particularly important in inaccessible regions like the poles. A major initiative in this area is POLES (Polar Exchange at the Sea Surface), an interdisciplinary investigation supported by NASA's global change program, the Earth Observing System (EOS).



Michael Gregg

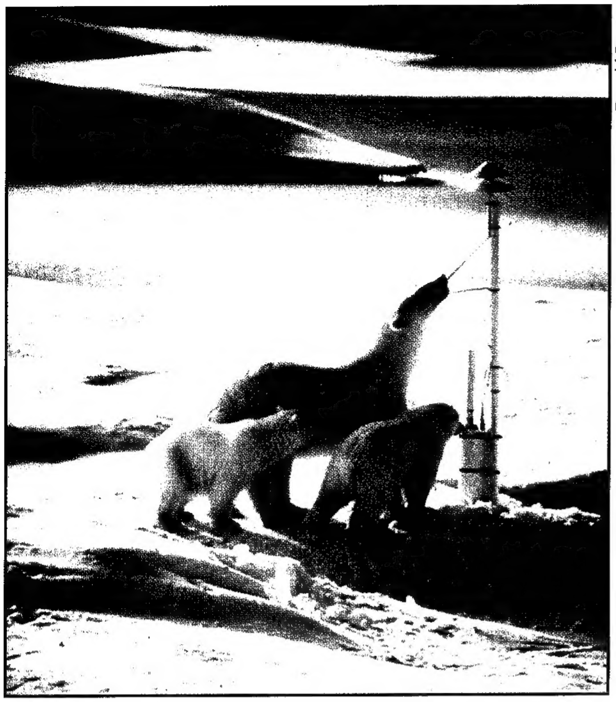
Earl Krause recovering the Advanced Microstructure Profiler (AMP) in front of Istanbul's Blue Mosque. The AMP was deployed from the R/V Bilim, *which is operated by the Marine Sciences Institute of the Middle East Technical University in Erdemli, Turkey.*

Ocean Physics

The Ocean Physics Department (OPD) has an international reputation for excellence in physical oceanography and ocean acoustics research. An aggressive program of instrument development and ocean measurement, combined with data analysis, theory, and numerical modeling, is applied to understanding heat fluxes, ocean currents, waves, turbulence, and mixing. Six OPD researchers hold joint appointments in University of Washington academic departments, teach and train graduate students, and serve as Principal Investigators on research projects funded primarily by grants from the Office of Naval Research (ONR) and the National Science Foundation.

Advanced instrumentation, designed and built by OPD scientists and engineers, is used to collect data from under the ice, along the coastlines, in estuaries and straits, and in the deep oceans of the world. For example, the Deep Lagrangian Float (DLF), designed to track the three-dimensional movement of water parcels from the near surface to the deep ocean, will be deployed in the North Atlantic as part of the Deep Convection Accelerated Research Initiative sponsored by ONR to study open-ocean deep convection, an important but poorly understood component of oceanic circulation.

The Modular Microstructure Profiler (MMP), a miniaturization of OPD's earlier Advanced Microstructure Profiler (AMP), relays vertical microstructure measurements through a twisted-pair


Donald Barton

Mother polar bear and cubs investigating a meteorological buoy. The buoy was deployed in the Arctic Ocean as part of the International Arctic Buoy Program.

cable for real-time, shipboard display. The MMP will be used in the first definitive study of shear and turbulence in the thermocline over the continental shelf, part of the Coastal Mixing and Optics Accelerated Research Initiative sponsored by ONR. To collect complementary horizontal measurements, the Shallow Water Integrated Mapping System (SWIMS) was developed. SWIMS, towed from the stern of a moving ship, has mapped the formation of large, breaking internal waves and eddies generated along the irregular topographical features of Puget Sound's Admiralty Inlet.

Close collaboration between OPD theorists and experimentalists strengthens research. Numerical and analytical models, for example, predicted the relationship between internal gravity waves and energy dissipation and mixing. The prediction was verified using measurements made by OPD instruments, and these results were corroborated by other research groups. An upcoming experiment will test new theories suggesting that solibores (internal solitary waves with distinctive remote-sensing signatures) draw energy from the larger-scale circulation and produce substantial mixing. Theorists and experimentalists will use SWIMS and MMP in a remote inlet in British Columbia to acquire the data necessary for further study.

Multidisciplinary acoustics research has focused on relationships between physical oceanography and ocean acoustics. The Multiple Discipline Group, which brings together OPD and other APL and UW scientists, is analyzing data from acoustic propagation experiments that combine extensive precise measurements of the ocean environment. This work has led to advances in understanding the general problem of wave propagation in random media.

APPLIED RESEARCH & TECHNOLOGY GROUP

The Laboratory's Applied Research & Technology (AR&T) Group comprises five interrelated departments with expertise in acoustics, signal processing, computer simulation, tactical oceanography, electronic systems, and ocean engineering. The AR&T Group applies research results to the solution of real-world problems. The programs complement and support work by the Navy R&D Centers, other university laboratories, and industry.

Simulation & Signal Processing

In recent years, the U.S. Navy has shifted the emphasis of undersea warfare research and development from technologies suited for deep-water, open-ocean operations to those needed in shallow water and littoral areas. Such areas are characterized by complex acoustic propagation, strong and highly variable noise and reverberation interference levels, and a potentially large number of biological and bottom-feature false targets. These effects complicate the detection of submarine and mine targets and make classification an extremely challenging problem.

The Simulation and Signal Processing (SSP) Department supports Navy efforts in mine countermeasures and antisubmarine warfare by providing innovative signal-processing solutions and by developing emulation/simulation systems for concept development and testing. Signal processing involves the manipulation, usually by digital computer, of acoustical, optical, and other types of signals. For example, acoustical signals received on submarine and surface ship sonars are processed to determine if other ships and submarines are nearby, and, if so, to ascertain their type and location. Data from mine countermeasure sonars and lasers are also processed to detect and classify mine-like targets and to map their locations.

Examples of current signal-processing work include development of beamforming and classification algorithms for the Clandestine Mine Surveillance System (CLAMSS) and development of torpedo detection and classification approaches for shallow-water environments. CLAMSS, funded by the Office of Naval Research (ONR), uses wideband, low-frequency sonar to locate and classify mines in shallow-water regions. The performance and system implications of different types of waveforms, beamforming, and image-processing algorithms are being explored. To provide optimum performance, signal- and image-processing methods must explicitly incorporate knowledge about the acoustic environment in which a given system is operating. CLAMSS seeks to understand and take advantage of the interaction between environmental effects (e.g., multipath propagation and scattering) and processing methods.

In torpedo research and development, the Mk 50 torpedo project office (PMO406) and the ONR torpedo guidance and control project are being supported. The Mk 50 work improves the classification and detection performance

of the torpedo in shallow-water environments. For this work, we are enhancing statistical classification approaches that have been developed at APL in past years under 6.2 Torpedo Guidance and Control funding. Models for both biological and bottom-related false targets are also being developed. These models are used in computer simulations to study the performance of new classification and detection algorithms.

One of the simulation projects, sponsored by the Naval Undersea Warfare Center (New London) and the Undersea Warfare Advanced System Technologies Office (USW-ASTO), is the Detection, Classification and Localization Acoustic Signal Processor (DCLASP). The goal is to develop a shallow-water simulation that generates high-fidelity acoustic data for simulated submarine sensors including towed, hull, and spherical arrays.

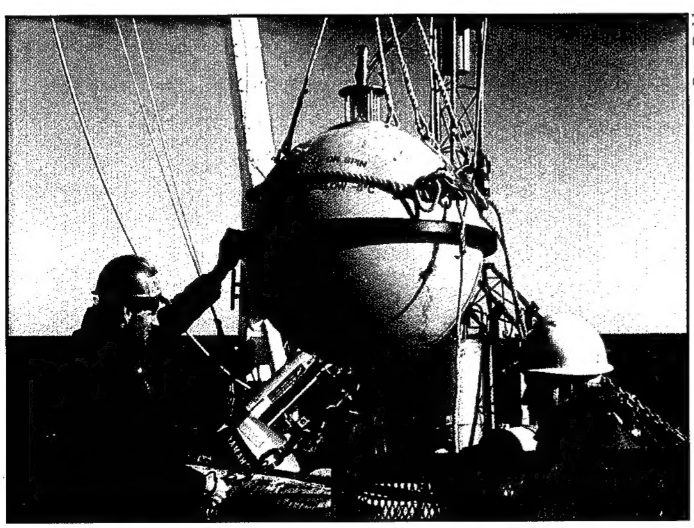
A long-term, ongoing simulation effort is the development of the Sonar Simulation Toolset (SST). The SST allows a sonar developer to synthesize realistic, multichannel active and passive sonar acoustic time-series data for development and testing of new signal-processing approaches. The SST package has been ported to a wide variety of workstations and provides a powerful, desktop synthesis capability to sonar designers.

Acoustics & Electromagnetics

Basic and applied research programs cover a wide range of acoustic and electromagnetics topics.

The research program in boundary scattering, for example, includes theory and modeling of acoustic interaction with the sea surface, experimental studies of scattering from bubble clouds, and temporal studies of scattering from the seafloor. High-frequency acoustic experiments are used to study sea-surface scattering and near-surface bubble loss, to gather bistatic scattering measurements of the bottom, and to image bottom properties such as biological and hydrodynamic effects and the penetrability of various bottom types. These measurements, and the models they help refine, are of interest to the torpedo and mine warfare communities.

The Acoustics and Electromagnetics (A&E) Department is a principal contributor to a broadly based effort to show that long-distance underwater acoustic transmissions can be used to monitor average ocean temperature. This Acoustic Thermometry of Ocean Climate (ATOC) program is establishing acoustic transmission and reception sites in the Pacific Basin in preparation for demonstration measurements.


Peter Dahl

Eric Boget and Vern Miller launch a wave buoy used by Peter Dahl in an environmental acoustics experiment.

High-power ultrasonics are used to study the role of cavitation in extracorporeal shock wave lithotripsy, a technique employed to destroy kidney and gall stones. This research will result in a better understanding of stone destruction mechanisms, which will lead to more effective treatment schedules and power dosages. The National Institutes of Health support our study of the risk associated with the clinical use of diagnostic ultrasound, which has demonstrated that many of the current clinical units produce potentially damaging acoustic cavitation under certain circumstances. Research is also under way on employing high-intensity ultrasound to influence chemical reactions (sonochemistry). In related work, we are examining the intriguing physics associated with single-bubble sonoluminescence, a phenomenon that may involve temperatures on the order of millions of degrees.

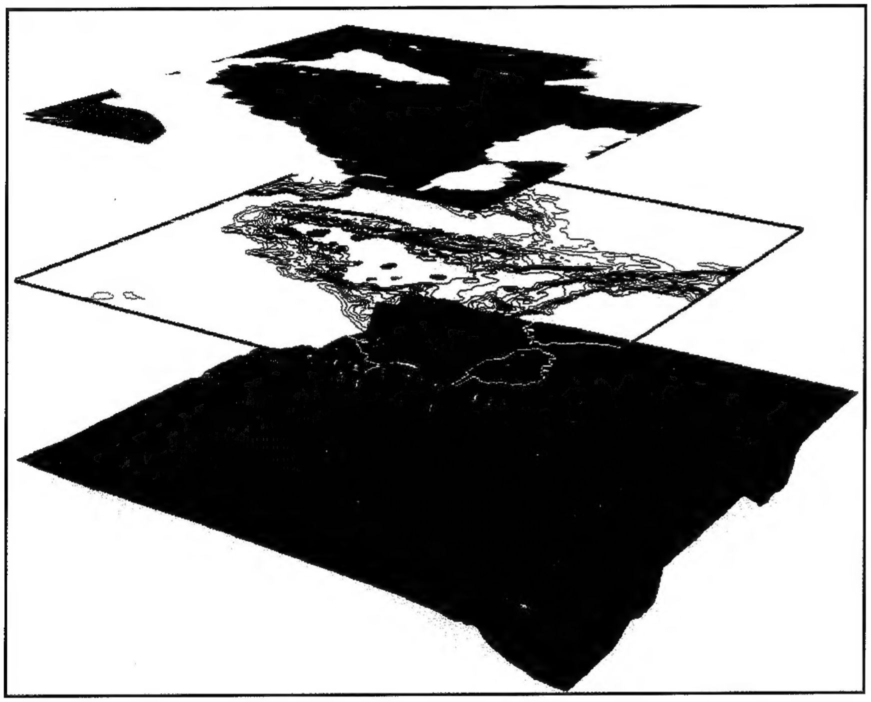
Microwave scattering and infrared sensing techniques are applied to studying the sea surface. Microwave scattering from isolated ocean patches is monitored by blimp-mounted radars, and infrared sensors are used to study small-scale heat flux at the dynamic ocean surface.

Included on the applied side of the department's work is support of the Naval Sea Systems Command ASW Test Program for the FORACS (Fleet Operational Readiness Accuracy Check Site) ranges, which test the accuracy of operational Navy systems; support includes performing site studies, developing new instrumentation, and maintaining the accuracy of existing ranges.

Environmental & Tactical Systems

The emphasis on shallow-water, littoral warfare has increased the importance of providing Navy commanders with timely and accurate information about environmental impacts on sensor and weapon systems. The Environmental and Tactical Systems (ETS) Department specializes in information management and decision support that improve the

effectiveness of tactical decision making. ETS-developed systems optimize the performance of Navy sensors and systems by understanding and describing the ocean environment. Regional environmental descriptions reduce the amount of time a vessel spends "in harm's way" and give Navy commanders the tactical advantage by increasing the accuracy of performance prediction tools.



Different views of the same bathymetric data are useful for multiple applications, including mission planning, navigation, and false-target analysis.

Knowledge of the coastal environment is also applied to fisheries and environmental issues. ETS-designed computer technologies and graphical user interfaces aid in measurement, detection, classification, information management, and decision-making based on the local ocean environment.

For the Office of Naval Research (ONR) and the Naval Research Laboratory (NRL), ETS developed a workstation testbed that explores the application of object-oriented environmental information management, remote processing, and advanced multidimensional visualizations. This Tactical Environmental Information System (TEIS) enables computer-based environmental decision aids to "learn" while operating so as to better communicate the results to Navy officers.

Components of TEIS are supporting Combatant Data Collection (CDC) as an environmental-parameters databank for the Navy's Advanced Environmental Acoustic Support (AEAS) Program. This "intelligent" databank provides missing information in littoral areas and is crucial to the use of CDC information. Also prepared was a comprehensive Arctic database of measured, low-frequency propagation loss with the supporting environmental and oceanographic data that are used for model development and evaluation.

For the U.S. Naval Oceanographic Office (NAVOCEANO), nonlinear-optimizer technology was used to automatically interpret combatant sonar data and to deduce environmental parameters for more accurate databases. Developments in the Geographical Information System (GIS) have been used to build new databases by storing and analyzing volume scattering data, bottom scattering data, and ice thickness data. We have also helped NAVOCEANO toward achieving its goal of a "paperless Navy" with DMARS (Digital METOC—Meteorology and Oceanography—Acoustic Reference Systems) on interactive CD-ROM for the Arabian Gulf and Gulf of Oman.

Working with the program executive office in charge of air antisubmarine warfare, clutter rejection has been improved and *in situ* measurements that support low-frequency active sonar systems in shallow water have been used. The department also assists the program office's communication with the Oceanographer of the Navy and ONR.

The Naval Personnel Research and Development Center (NPRDC) was provided with environmental acoustic support for the Interactive Multidimensional Analysis Trainer (IMAT). Knowledge of environmental models and data is combined with new interfaces to improve the system's performance.

ETS supports the Commander of the Naval Meteorological and Oceanography Command (CNMOC) and the Ocean and Atmospheric Master Library (OAML) by developing, documenting, and evaluating Navy standard acoustic models. ETS department members serve on a variety of panels and committees, including OAML's Software Review Board and its High-Frequency Model Review Committee.

Funded by Washington Sea Grant, an interactive multimedia CD-ROM on Puget Sound is being created. This is a new means of communicating science to the public for better management and understanding of the ecologically endangered Puget Sound. The Washington Technology Center has supported the department's effort to build a computer-aided training tool for firefighters managing hazardous waste materials.

Also under development within ETS is an expert system for analyzing fisheries survey data so that nonstatistically trained fisheries biologists can estimate fish abundance from survey data. Multivariate statistical techniques created from sonar images allow the identification of fish schools to the species level, improving the accuracy of abundance estimates and allowing fishermen to bypass unwanted catch.

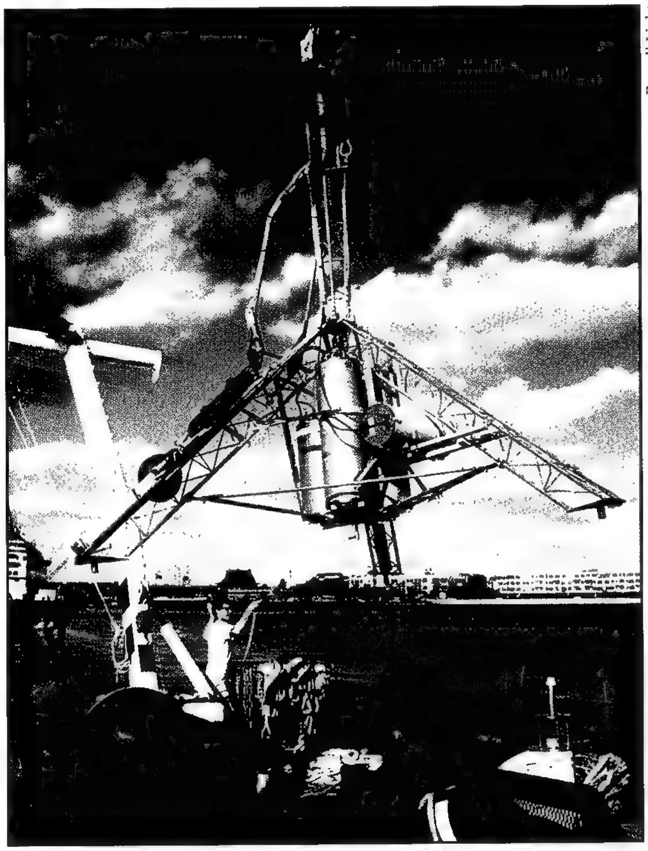
Ocean Engineering

Hands-on experience at sea is a hallmark of the Laboratory, and the Ocean Engineering (OE) Department, where much of this expertise resides, is a resource to APL and the Navy.

Department engineers have extensive experience in the design, fabrication, and deployment of complex systems in the deep ocean and in coastal waters. In a recent project, the department provided engineering support for studies of acoustic and physical seafloor properties in the coastal zone. This work involved deployment of a large APL-designed instrument platform that rests on the bottom, with sensor arrays tethered to a ship positioned in a four-point moor. The project was a collaborative effort with the Naval Research Laboratory and the Defence Research Agency of the United Kingdom. The environmental acoustic data are applicable to mine warfare planning.

APL pioneered the development of an unmanned underwater vehicle for taking scientific measurements and has continued to use such systems to gather data in unique environments. Working with the Polar Science Center, the OE Department developed a small autonomous vehicle that has made over 70 runs during the past five years to gather conductivity-temperature-depth (CTD) data under the Arctic ice. There have been 20 successful deployments of an OE-developed variant of the vehicle that deploys a light line for several thousand feet to assist in placing instruments between ice holes more than 1000 m apart.

The department also supports research and testing of antisubmarine warfare (ASW) systems at ice camps in the Arctic. APL serves as expedition coordinator and hosts other university and Navy laboratories. The APL team selects the test sites, constructs airplane runways, designs and fabricates camp housing and equipment, and provides historical and *in situ* environmental data. Specially trained divers assist in launching and recovering test vehicles through holes in the ice bored by thermal melters. Instruments are tracked with a portable, underwater acoustic tracking range.



Russell Light

The Benthic Acoustic Measurement System (BAMS) tower being readied for use in the Key West experiment of the NRL Coastal Benthic Boundary Layer Program.

In another project, we are using finite element computer models to evaluate structural failures of the rubber windows on bow- and keel-mounted ship sonar domes. These simulate the response of the window to actual operating conditions to reveal failure modes and develop more robust designs. This technology is also being used to develop a new type of sonar dome in which a fiberglass-rubber composite replaces the conventional rubber-steel structure.

The department also has a program for evaluating corrosion and failure of components on Navy submarine, surface-ship, and bottom-mounted sonar systems. We inspect cables, connectors, and transducers, autopsy in-service components, test and autopsy newly designed components, identify failure modes and mechanisms, and recommend solutions. Video documentation provides an instantaneous, permanent record that elucidates cause, effect, and corrective action for program managers, field service personnel, and Fleet operators.

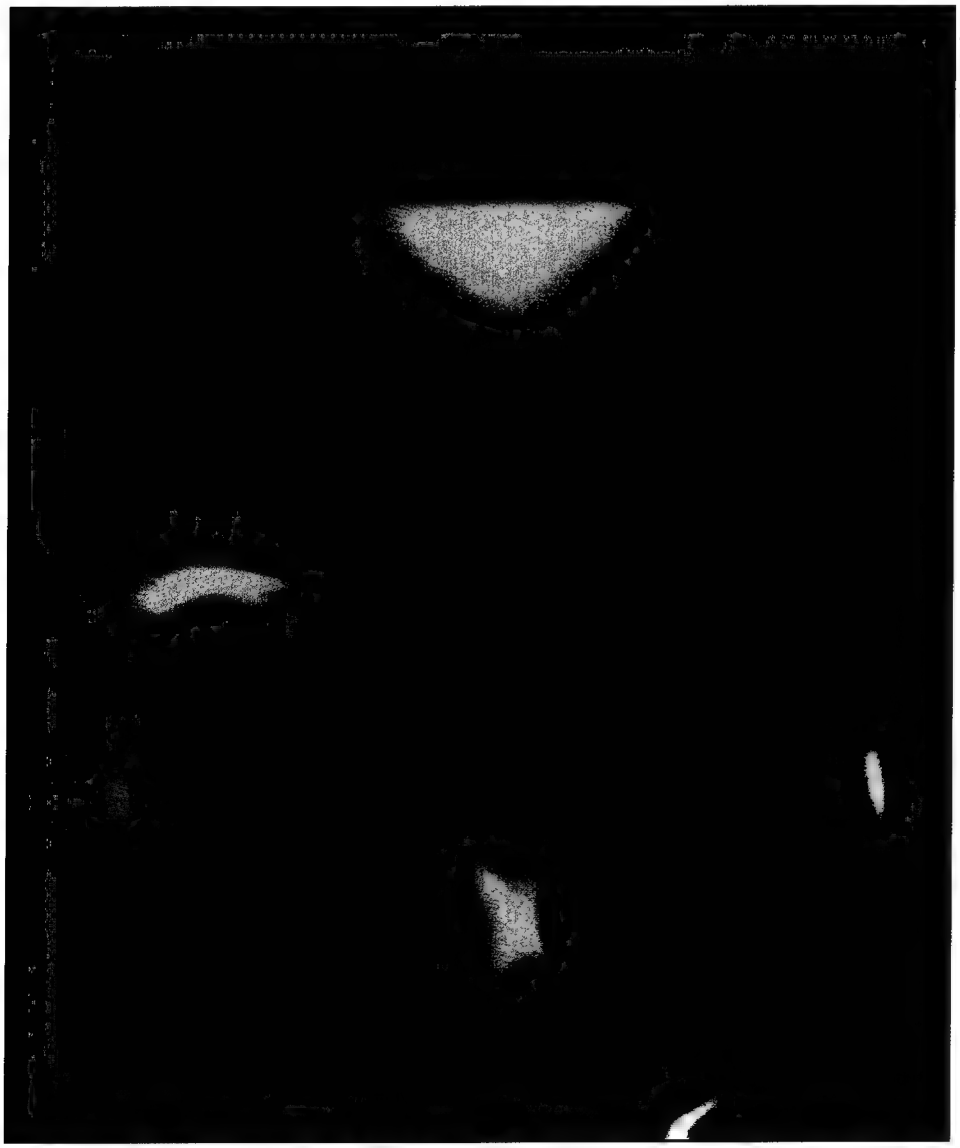
Electronic Systems

Most underwater sensors and data collection systems are dependent on increasingly sophisticated electronic circuitry. The central theme of the Electronic Systems (ES) Department is the development and application of advanced concepts in electronics, including the design and construction of prototype systems. Expertise in the department includes analog and digital circuit design, high-speed data recording and processing, fiber-optic networks, and the design of special-purpose acoustic transducers. Applications of special importance to the Navy include environmental acoustic survey systems, acoustic data recording and processing systems, high-resolution imaging systems for diver-held sonars and autonomous underwater vehicle navigation, and 3-D underwater acoustic tracking ranges. The department also designs and fabricates scientific instrumentation used for research, testing, and analysis.

The Sound of Light

A group of APL scientists has gone from studying sonar performance in the ocean to researching the industrial applications of ultrasound. The leap is not as broad as it may seem: The same basic physical principles may be applied to many different types of scientific problems, and research often evolves into new areas along unexpected paths.

For Department Chair Larry Crum, Senior Physicist Ron Roy, Senior Mathematician Pierre Mourad, and their colleagues in the Acoustics and Electromagnetics (A&E) Department, the common element in these seemingly disparate research areas is bubbles. Bubbles created by wind and waves scatter sonar signals that bounce off the ocean surface. Understanding the physics involved in this process is required to predict sonar performance. The group's interest in the acoustic effects of bubbles, including sea surface bubbles, grew out of earlier work on acoustic cavitation, a phenomenon wherein microscopic cavities form when water is subjected to ultrasonic waves. The cavities fill with gas that was originally dissolved in the water, giving rise to bubbles.



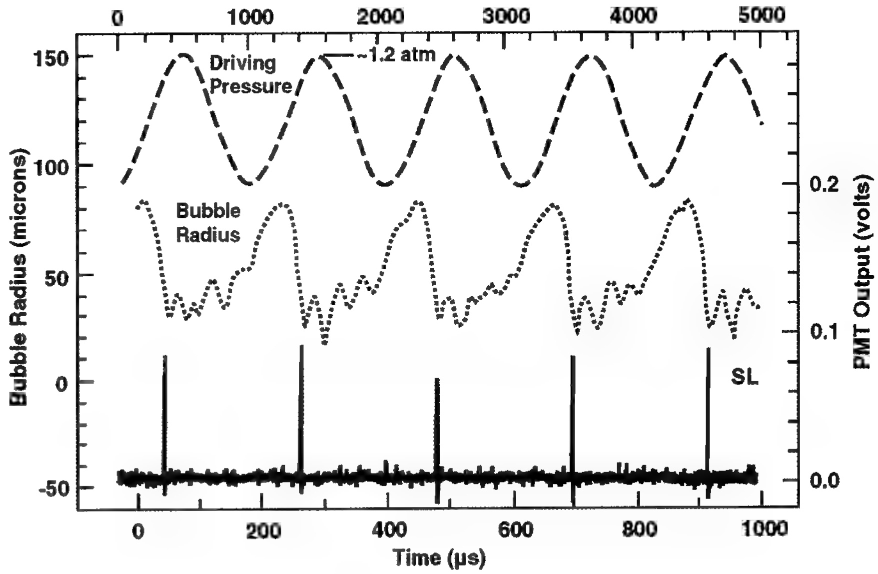
Lawrence Crum

Multiple-bubble sonoluminescence (MBSL) produced by an ultrasonic horn at a frequency of 20 kHz. For this photograph, which is a double exposure that shows both the low-intensity MBSL as well as the horn itself (orange), luminol was added to the water to produce more light in the visible region of the spectrum.

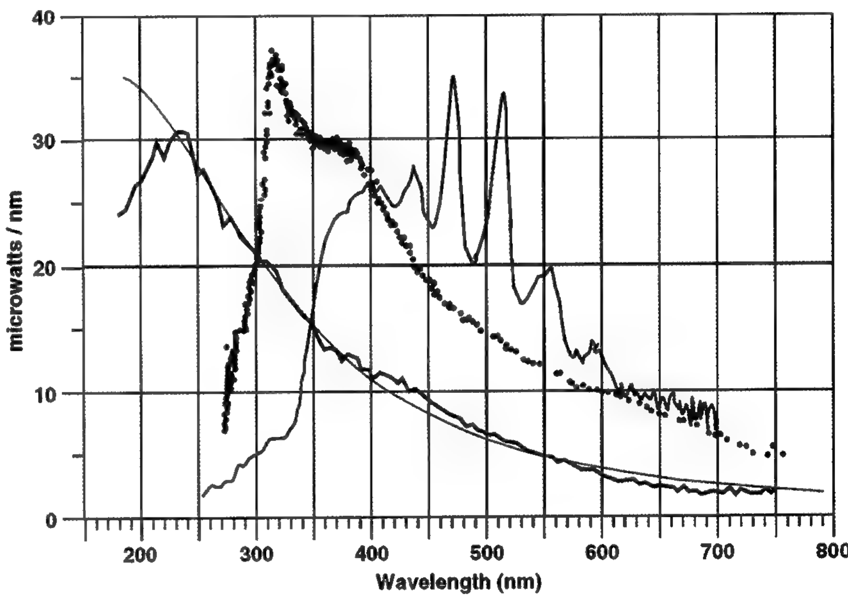
These ultrasound-generated bubbles are fascinating to study because, if conditions are right, the newly formed bubbles can be driven to pulsate violently. As the bubbles collapse, they produce an extremely brief flash of light, the product of what is believed to be an enormous concentration of heat energy within the bubble. The phenomenon is known as sonoluminescence. Just how much heat is present is the subject of vigorous scientific debate, a controversy that the APL team may help resolve. APL's work in sonoluminescence is already widely known and has been discussed in journals such as *Science* and *Physical Review Letters*, science magazines such as *Scientific American*, *Physics Today*, *Science News*, and *New Scientist*, and many newspapers, including *The New York Times*, *The Dallas Morning News*, and *The Seattle Times*.

Although scientists have known about sonoluminescence for more than 60 years, the complexity and randomness of multiple-bubble cavitation fields make the phenomenon difficult to study with precision. Recent improvements in experimental techniques have opened up new avenues for research. An important breakthrough occurred in 1989 when Felipe Gaitan, a graduate student of Crum's at the University of Mississippi, developed a technique for producing a single, stable bubble that could be acoustically suspended. Gaitan discovered that light emission correlated with bubble collapse and that a single bubble could be made to flash in synchrony with the sound-wave patterns. This work, and the predictable, repetitive nature of single-bubble sonoluminescence, paved the way for other groups to make a series of exciting discoveries about sonoluminescence.

The synchronous relationship between acoustic pressure waves (red dashed line), bubble radius (green dashed line), and emissions from single-bubble sonoluminescence (blue line). The blue spikes indicate light emissions that occur when the bubble collapses.



Below: Sonoluminescence spectra. The red curve is for multiple-bubble sonoluminescence (MBSL) in dodecane; the blue dots are for MBSL in water; the green curve is for single-bubble sonoluminescence (SBSL) in water; the smooth gray line is the tail of the curve typical of blackbody radiation. The apparent match between the SBSL curve and the blackbody radiation curve is the source of speculation that SBSL may be linked to temperatures eight to ten times hotter than the surface of the sun.



What they found was not only controversial, it was also astonishing. The brief flashes of light were linked to temperatures inside the bubble as high as 10,000 degrees Celsius, as hot as the surface of the sun. Some researchers think the temperatures inside the bubbles might be as much as eight to ten times higher than this.

One of the keys to understanding sonoluminescence is the spectrum of light that is emitted. However, water absorbs a portion of the spectrum, thereby obscuring important information. To capture the missing pieces of the puzzle, Roy, Mourad, and Crum have obtained funding from the Office of Naval Research (ONR) and the National Science Foundation (NSF). APL Post-Doctoral Scientist Tom Matula and Physicist Steve Kargl are also involved in the ONR project, which is proceeding on both experimental and theoretical fronts. On the experimental side, laboratory tests are being designed to illuminate the differences and similarities between single-bubble and multiple-bubble sonoluminescence. An effort to develop a state-of-the-art laser-scattering apparatus that can precisely track the motion of a near-microscopic bubble is also under way. On the theoretical side, the effort is aimed at modeling the gas dynamics of bubble collapse, focusing on the formation and evolution of shock waves within the imploding cavity.

The extremely short intervals of high temperatures that occur during bubble collapse can create some exotic chemistry that holds promise for industrial applications. Both Crum and Roy are working with private industry to develop ultrasound techniques that break down hazardous materials, produce exotic nanoparticles, and enhance ultrasonic cleaning techniques. Another application uses ultrasound as a catalyst. An example is the industrial chemical process of reducing potassium iodide to iodine. The high concentrations of energy generated in the bubbles can cut the reaction time from hours to a few minutes, or even milliseconds.

Sonochemistry has also been applied to manufacture small amounts of amorphous (noncrystallized) iron, a product of considerable commercial interest because it is useful in accelerating chemical reactions. Iron normally possesses a crystalline structure made up of well-ordered molecules. The intense energies available from bubble collapse are powerful enough to prevent molten iron from crystallizing before it solidifies.

An Historic Expedition to the North Pole

The Applied Physics Laboratory has for many years been at the forefront of ocean research in the Arctic, yet its polar oceanographers are often frustrated by their inability to obtain data from important, yet unstudied, regions. For example, computer models indicate that the Arctic Ocean plays a key role in global climate change, but a dearth of measurements from the region makes it difficult to test this theory.

Scientific expeditions to the northern polar regions are extremely expensive owing chiefly to the inaccessibility of the Arctic Ocean and the harsh climate. When an expedition is planned, scientists from many disciplines converge to take advantage of the opportunity. Thus, when the Canada/U.S. 1994 Arctic Ocean Section, a joint U.S./Canadian icebreaker expedition across the top of the Arctic, got under way in the summer of 1994, some 70 scientists conducting over 50 different scientific programs were represented. Polar bears and pesticides, cod fish and seafloor sediments, dirty ice and warm water: all were studied.

APL Polar Science Center Principal Oceanographer and Professor of Oceanography Knut Aagaard was the expedition leader while also pursuing his own research on the physical oceanography of the Arctic Basin. He was in charge of the water sampling program with the goal of mapping the water structure of the Arctic Ocean using clues gleaned from measurements of water temperature, salinity, and tracers. Parcels of water with different origins often retain their identity as they circulate through the world's oceans: Salinity and temperature are like fingerprints, bearing the mark of origins that may be as distant as the tropics.

Although much of the expedition's work had to await land-based laboratory analysis, some analytical work was conducted on board. One surprise for Aagaard was the discovery of a much

Knut Aagaard

Knut Aagaard (left, in orange flight suit) and a U.S. Coast Guard helicopter crew install a satellite-tracked buoy on the ice. Aagaard, of APL's Polar Science Center, served as the expedition leader.

Knut Aagaard

Expedition vessels U.S. Coast Guard Cutter Polar Sea *and the Canadian Coast Guard Ship* Louis S. St.-Laurent, *the first North American surface ships to reach the North Pole. This milestone, achieved on August 22, 1994, was capped by an unplanned rendezvous with the Russian icebreaker* Yamal.

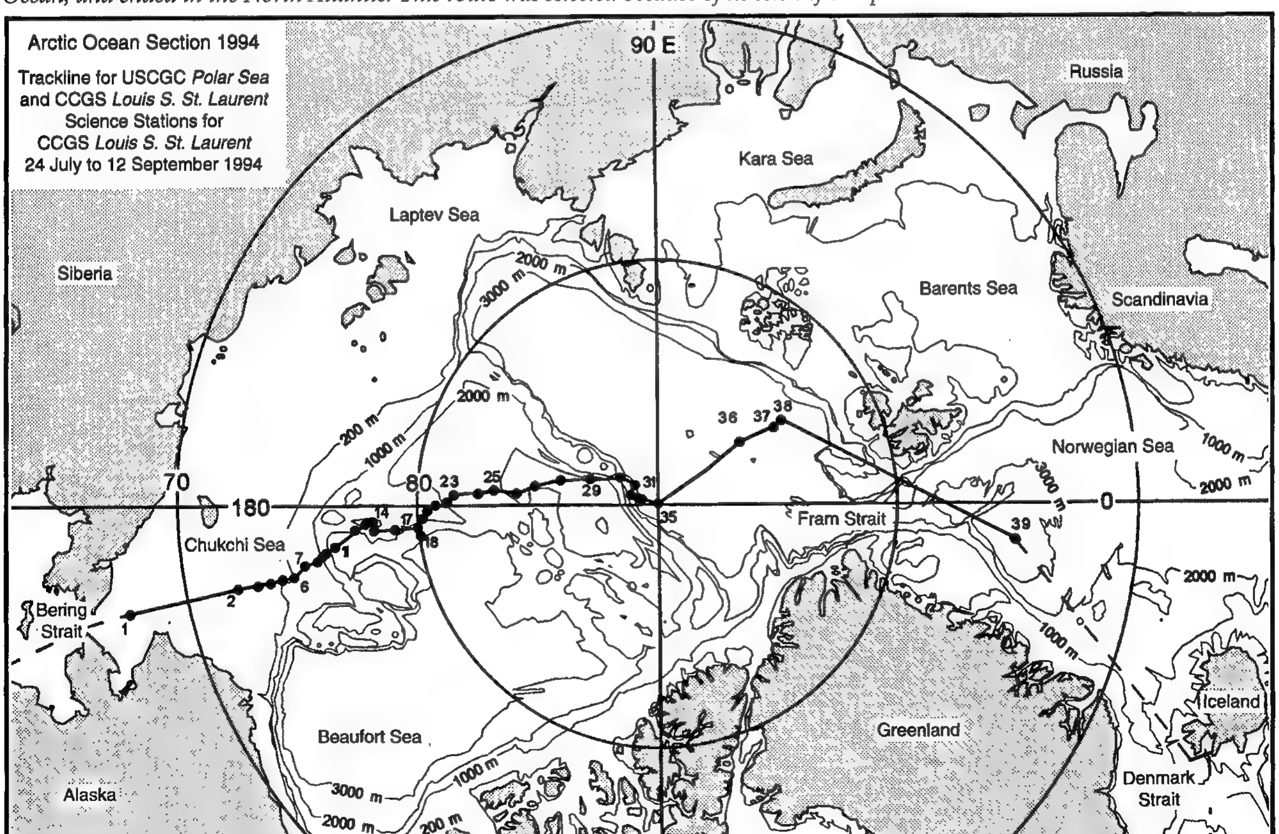
warmer-than-expected layer of water between 100 and 2000 m depth. After a post-cruise analysis, Aagaard and his colleagues have concluded that this water most likely came into the Arctic from the Atlantic Ocean in the late 1980s. While Aagaard does not believe this warmer water is an indication of global warming, it is highly useful as a tracer; mapping its occurrence reveals how water enters and moves within the Arctic Basin.

The Canada/U.S. 1994 Arctic Ocean Section was not only a scientific success, it also made history. The two expedition vessels, the Canadian Coast Guard Ship *Louis S. St. Laurent* and the U.S. Coast Guard's *Polar Sea*, became the first North American surface ships to reach the North Pole and the first ever to reach it by the long and difficult route from the Pacific. There, at the top of the world, the expedition spent 28 hours undertaking an extensive sampling program to collect data on the concentrations and distributions of contaminants such as pesticides and radioactive materials that affect the food chain and the environment of the Arctic Ocean.

Organochloride analysis of these and other expedition samples will increase biologists' understanding of how contaminants carried into the Arctic Ocean from as far away as the tropics end up in many of Canada's northern residents, both human and animal. Identifying the origin of sediments found trapped within sea ice will also add to the knowledge base on contaminant transport, while long cores of bottom sediments collected by marine geologists will yield information on the region's geologic history. As Aagaard emphasizes, the benefits of such interdisciplinary work include a synthesis of scientific interpretations: Each discipline has unique and vital contributions to knit into what will be the most extensive and cohesive view of the Arctic environment ever developed.

The expedition's principal sponsors in the U.S. were the National Science Foundation, the Office of Naval Research, the U.S. Geological Survey, and the U.S. Coast Guard. Canadian sponsors included the departments of Fisheries and Oceans, Environment, and Indian and Northern Affairs, together with the Canadian Coast Guard.

Trackline for the Canada/U.S. 1994 Arctic Ocean Section, which began in the North Pacific, traveled across the Arctic Ocean, and ended in the North Atlantic. This route was selected because of its scientific importance and richness.



From the Gulf of Oman to Puget Sound: Multimedia at APL

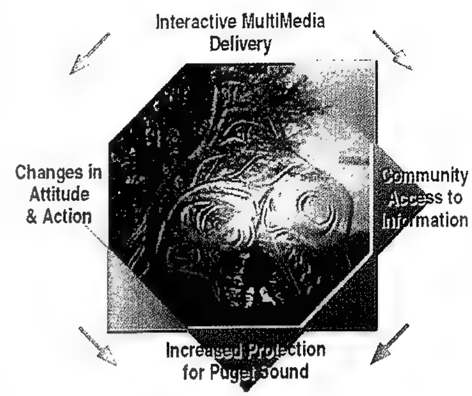
The information-age technology that has shrunk an encyclopedia to the size of a compact disc (CD) is being applied at APL to the manuals, publications, and charts the U.S. Navy needs to operate throughout the world. This approach saves weight and space on Navy vessels and presents complex information in an easy-to-use form for Navy tacticians. Another project is using this technology to inform and educate the general public about Puget Sound.

To enhance operations at sea and the performance of its weapon systems, the Navy employs complex sensors to collect data on the ocean and atmosphere. For many years, APL, working with the Naval Oceanographic Office (NAVOCEANO), has put these data into publications that describe the environment where Navy ships and aircraft operate. The Submarine Tactical Operations Reference Manuals (STORM) and the Environmental Guides for surface ships are substantial, even daunting, assemblies of data that include sonar conditions, currents, and bottom types. APL recognized the advantages of using CD-ROM technology to store this information and proceeded with support from NAVOCEANO.

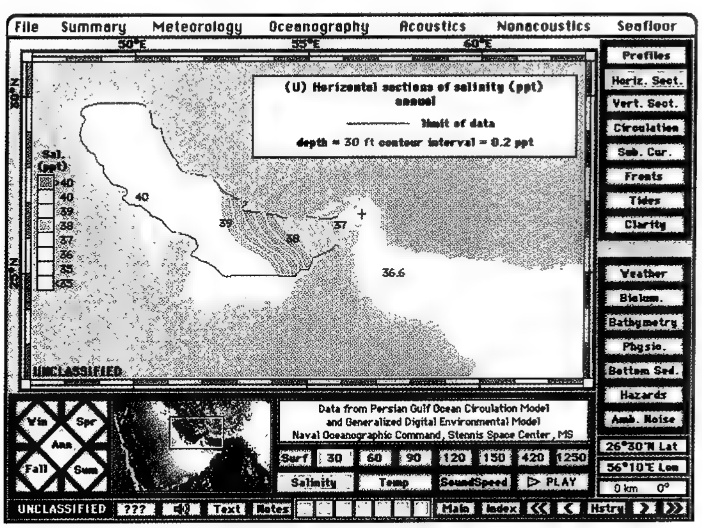
The APL team, led by ETS Department Head Robert Miyamoto, has reorganized the information into a computer-based, interactive, multimedia format that includes full-color displays, animation, and sound. Conversion to this format has increased the usefulness of the publication by allowing a user to navigate quickly through data in a nonlinear fashion, rather than plowing through page after page of rigidly organized tables, graphs, and text. The end product is an easy-to-use and effective mission planning tool that weighs less than 2 ounces and can be cheaply replicated and revised.

The first phase of the project has focused on the Arabian Gulf and the Gulf of Oman, an area of political and military concern for the U.S. The APL-designed guide provides political and historical background, as well as information about the physical environment. With the click of a computer mouse, the user is guided through the complex coastal environment of this region to learn about the meteorology, oceanography, acoustics, and seafloor. Another click and the region's strategically important ports are highlighted on a map.

Such multimedia displays enhance the learning process: Color displays with sound and motion activate more learning centers in the brain than does reading text from a printed page. Each user is free to find paths through the material that are most suitable to his or her learning style. Given the generation of youth that has grown up with video games, it is no surprise that today's users feel comfortable with the product.



Sample window from the Puget Sound Multimedia CD-ROM. This project is converting hard-copy information on Puget Sound into a user-friendly and interactive multimedia format.



Demonstration screen from the multimedia Digital Environmental Guide to the Arabian Gulf. Users may click on-screen buttons to navigate through the CD-ROM.

While APL has provided military planners with better access to information about foreign waters, the Laboratory has undertaken another multimedia project that will inform residents of the Puget Sound area what's going on in their own watery backyard. Where is it safe to harvest shellfish? Is there a waterfront park in West Seattle? Where will an oil spill spread?

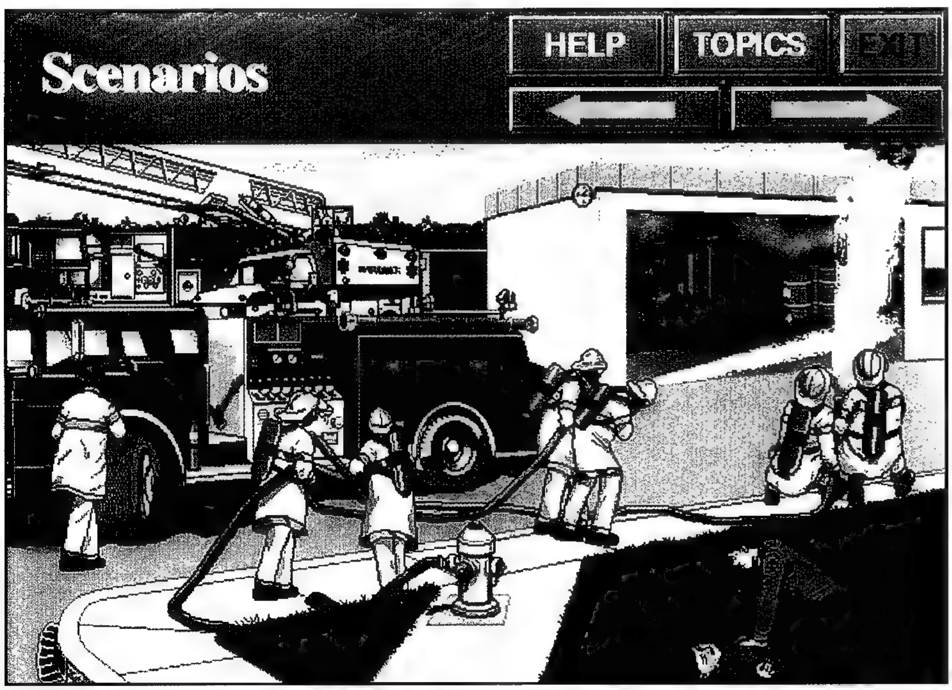
This type of information, in a colorful and lively interactive format, will be available on the Puget Sound Multimedia CD-ROM, funded by Washington Sea Grant. Users will include libraries, schools, state agencies, marine centers and museums, and sailors. The ETS team of Patricia Hardisty, Mark Stoermer, Bill Kooiman, and Troy Tanner is converting information from sources such as the Puget Sound Environmental Atlas and publications of local environmental agencies into the easy-to-use and affordable CD-ROM format. When the project is completed in spring 1997, the sound of waves lapping the shores of Puget Sound will emanate from computers throughout the region.

Computer-Based Training for Firefighters

In 1989, motivated by a Seattle firefighter's death while trapped in a burning building, APL began working with the Seattle Fire Department to develop a portable electromagnetic system to locate downed firefighters. In ensuing discussions with Seattle Fire Department personnel, APL Simulation and Signal Processing Department Head Jim Luby and Senior Electrical Engineer Greg Anderson became aware of another need: training in the handling of hazardous materials. Several years later, when the Laboratory began to exploit the capabilities of CD-ROMs for digitizing Navy environmental data, Luby and Anderson recognized the potential of that medium to address the training issue. The result is a CD-ROM training program that is APL's first joint venture with a private company leading to a commercial product.

Fire departments across the nation are concerned about potentially catastrophic hazardous materials accidents. For example, improper handling of a leak from a butane tanker in Tennessee caused an explosion that killed 17 people. Adequate training of emergency response personnel could have prevented this accident, as demonstrated by an episode in Seattle: a fire aboard a ship carrying 2000 gallons of ammonia was properly handled, and the evacuation of 50,000 residents was avoided.

Recognizing the importance of equipping firefighters with the detailed knowledge needed to manage hazardous materials accidents, the Occupational Safety and Health Administration (OSHA) has established an 8-hour minimum firefighter hazardous materials (HazMat) training requirement. While vital, this requirement has created an additional financial burden on fire department training budgets already thinly stretched. The HazMat CD-ROM is a cost-effective, computer-based training method, a self-contained program that holds the trainee's interest. Not just a reformatted textbook, the CD-ROM makes maximum use of the computer's flexibility, allowing a learner to follow his or her own learning paths. A multimedia approach, which combines sound, graphics, animation, and text, reinforces learning and stimulates interest. Lessons are enhanced with video footage from actual hazardous material spills and incidents. Student records are tracked automatically.



Scenario taken from APL's HazMat CD-ROM for firefighter training. The interactive, multimedia format allows learners to move through instructional material at their own pace and to receive training at the station between fires. It eliminates the high cost of taking firefighters out of service for classroom training.

The project is supported by APL and the Washington Technology Center (WTC), a state-funded organization on the University of Washington campus whose mission is to encourage commercially promising technology development of direct benefit to the economic vitality of Washington State by fostering university-industry partnerships. As a condition of funding, WTC requires a plan to commercialize the product once the development phase is complete. APL partnered with Pacific Interactive, a small firm in Bellingham, Washington, specializing in the design and production of multimedia safety-training products on topics that include fire fighting and hazardous materials.

Under the direction of Anderson, APL has undertaken the research end of the project, identifying the most effective methods of teaching and organizing the materials. Pacific Interactive will take the products to market. In the process, they will create animated scenarios from the two-dimensional graphics, or still scenes, designed at APL.

Anderson and Luby perceive the need for computer-based training in other organizations. For example, the Navy and companies such as Westinghouse Hanford face huge hazardous-material cleanup tasks and require extensive training programs.

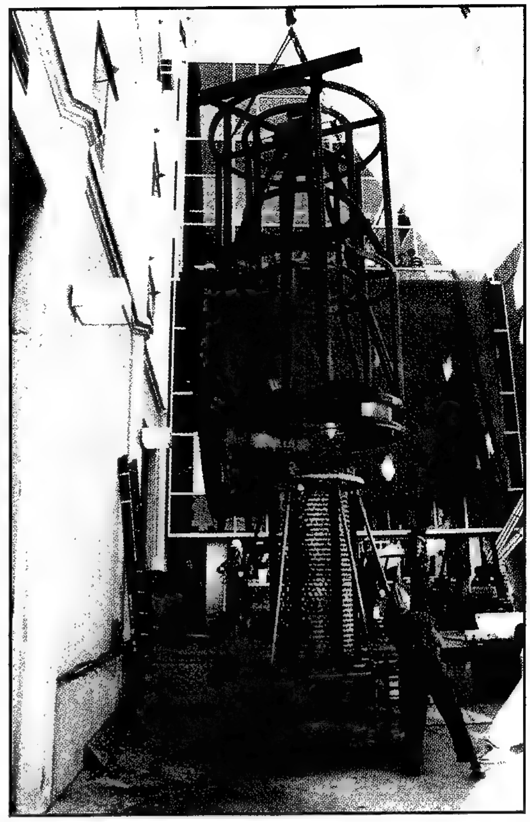
Measuring Ocean Temperature with Sound

Using sound to measure ocean temperatures, APL scientists are monitoring global climate change, a controversial topic that draws responses ranging from sincere concern to outright disdain. Although isolated measurements indicate the earth's climate is warming, it is impossible to generalize these to the entire globe. Because global-scale direct measurements are prohibitively expensive, an alternative, indirect method, as offered by the Acoustic Thermometry of Ocean Climate (ATOC) program, is needed.

The basic principle of acoustic thermometry is that sound travels faster through warm water than through cold water. If the time for sound to travel between two points in the ocean is measured over a sufficient period of time, then temperature changes should show up as changes in travel time, with shorter times meaning rising temperatures. The oceans will warm if there is a rise in atmospheric temperature due to the buildup of greenhouse gases.

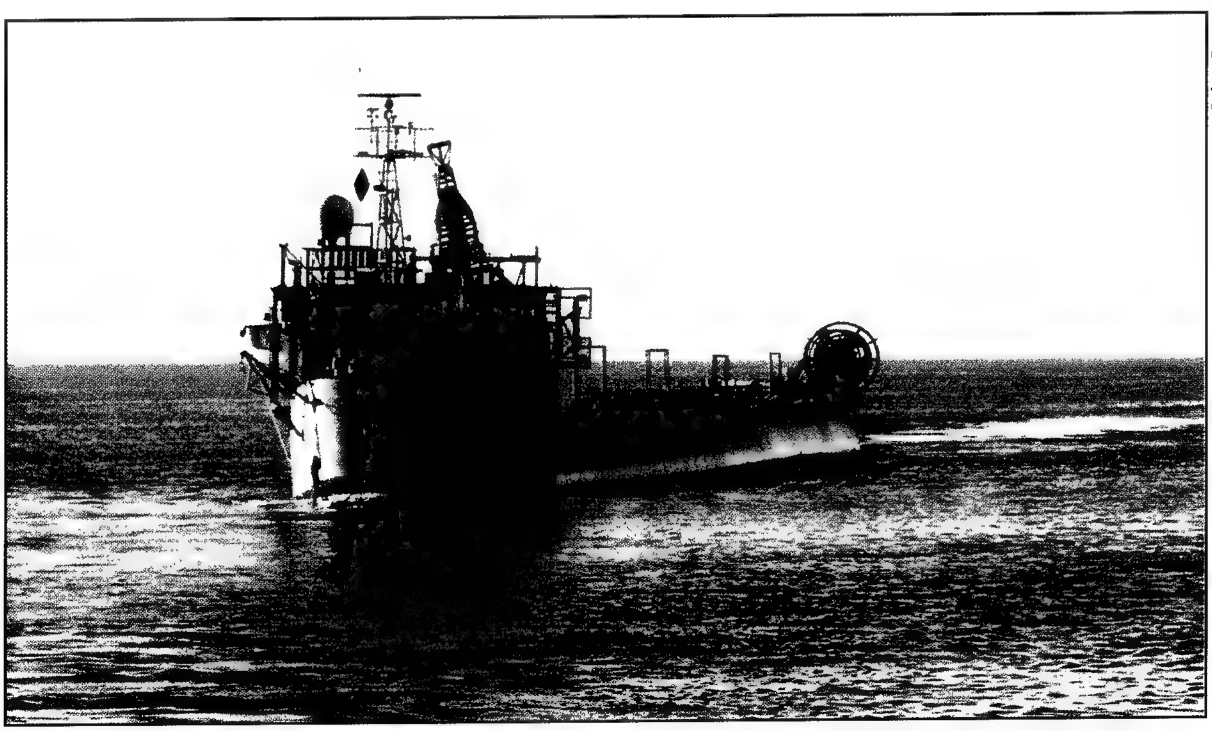
A major advantage of the ATOC approach is that relatively few stations are needed to cover large areas. A sound channel in the world's oceans allows sound to travel across entire ocean basins with minimal loss of energy. Therefore, a few acoustic sources and a few receivers, strategically placed, give excellent coverage of large areas. Furthermore, because there are many acoustic paths in the vertical between any given source-receiver pair, the ocean temperature at many depths is simultaneously sampled.

The Laboratory is one of 12 U.S. institutions in a seven-nation team participating in ATOC. Project leaders at APL are Director Bob Spindel, Principal Physicist Jim Mercer, and Senior Oceanographer Bruce Howe. The project is funded by the Advanced Research Projects Agency's (ARPA) Strategic Environmental Research and Development Program (SERDP), which was established when Congress directed the Department of Defense to expend a portion of its budget on environmental issues strategic to the well-being of the nation.



Dorothy Lowell

The ATOC source frame with protective shroud and its "garage" were designed and fabricated at APL. Here, at the APL loading dock, the garage is being lowered over the source frame in preparation for shipping.



Robert Drever

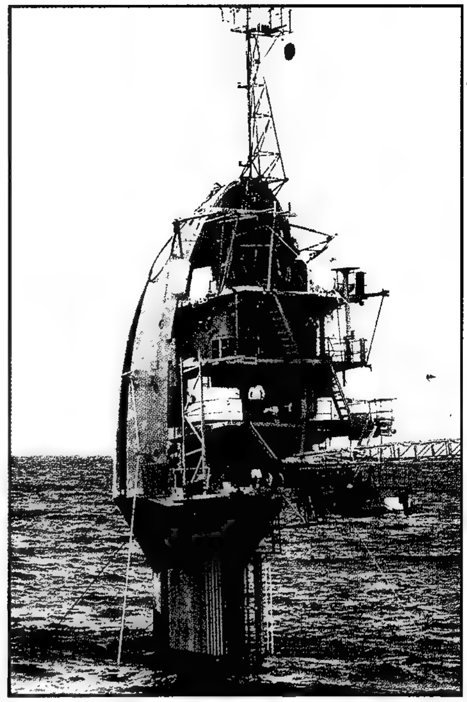
R/P FLIP *under way in the Pacific with the ATOC source mounted on the aft end of the vessel.*

The project took an important step in November 1994 when a sound source was tested in the Pacific, near the Jasper Seamount, 340 miles southwest of San Diego. This site was chosen partly out of concern for the possible effects of the sound signals on marine mammals, as Jasper Seamount is an area with little marine mammal activity. Nevertheless, marine mammal observers were present during all transmissions of sound.

The source was deployed from the Floating Instrument Platform, R/P *FLIP*, operated by the Marine Physical Laboratory of the Scripps Institution of Oceanography. *FLIP* was towed to the experiment site in its horizontal position and then rotated to the vertical, where it became, in effect, a spar buoy, its motion hardly affected by waves and swell. The ATOC source mounted on the lower end of *FLIP*, 90 m below the ocean surface, was then lowered on a wire to 650-m depth.

The *FLIP* experiment had two goals: to test the acoustic source at the proposed working depth and to determine the effect of the ocean's internal waves, which are known to distort sound, on long-range, low-frequency transmissions. The signals were successfully detected and recorded by vertical line arrays, the Navy's Pacific SOSUS arrays (hydrophones used by the Navy for submarine surveillance), and hydrophones as far away as New Zealand. Interaction of the sound signals with internal waves caused fewer problems than anticipated.

In the next step for the project, two acoustic sources are scheduled for deployment in the summer of 1995, one off the Hawaiian island of Kauai and the other off the coast of California. Situated in the sound channel to take maximum advantage of the favorable propagation conditions, the sources will emit low-frequency (60 to 90 Hz) sound, a pitch comparable to the lowest notes of a cello.



Robert Drever

R/P FLIP *rotated into the vertical position from which the ATOC source was deployed to 650-m depth.*

Sensing the Changes in Polar Climates

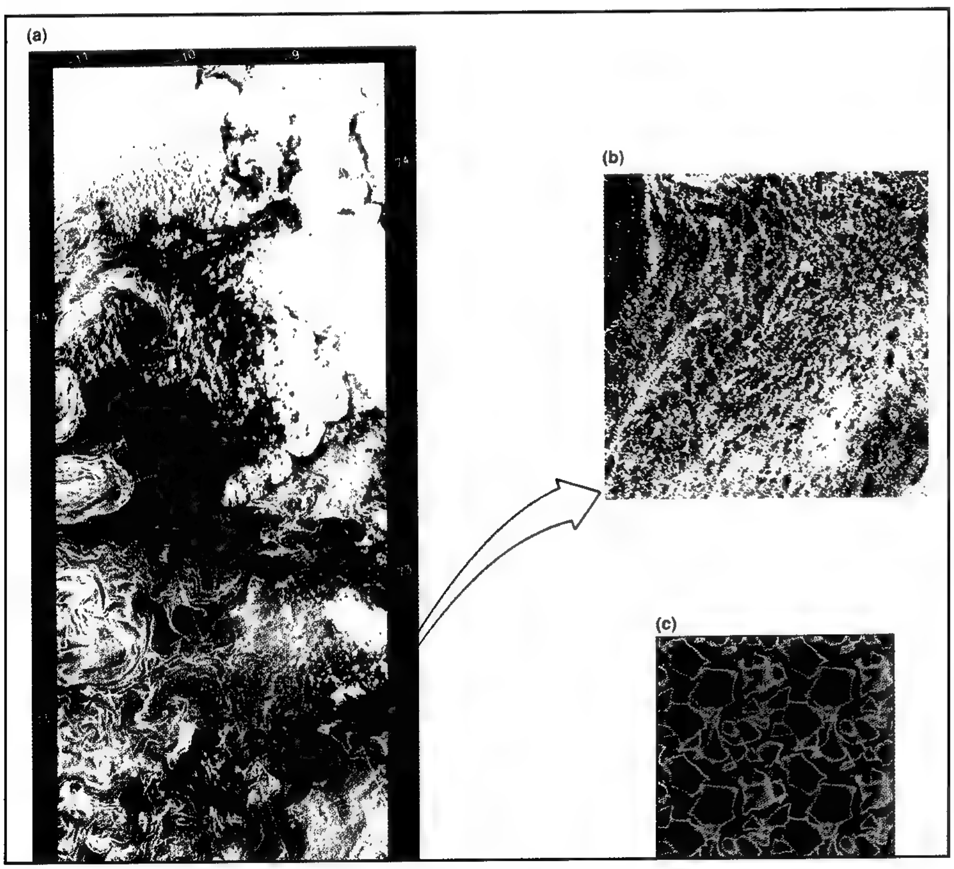
Scientists in APL's Polar Science Center are participating in NASA's Earth Observing System (EOS) study of the interaction of the ocean, sea ice, and atmosphere. EOS is a long-term, primarily satellite-based, program to determine the extent, causes, and regional consequences of global climate change. The ocean is a priority area because the exchange of energy, water, and chemicals between the ocean and atmosphere and between the ocean's different layers plays a critical role in maintaining climate balance.

Led by Drew Rothrock, Principal Research Scientist in the Polar Science Center and Associate Research Professor of Oceanography, a multi-institution team forms the Polar Exchange at the Sea Surface (POLES) component of EOS. The effects of global warming are likely to be seen first at the poles, because computer models of climate and general circulation predict that the greatest response to an increased concentration of atmospheric carbon dioxide, a major component of the so-called greenhouse gases, will occur in the polar regions. The accuracy of these models is uncertain, but can be improved through better use of satellite observations.

Three-dimensional model output of shallow convection in the Arctic Ocean. (Graphic courtesy of D. Smith)

Combining satellite data with field observations, POLES is determining the rates of exchange of heat, moisture, and momentum across the surface of the polar oceans and between the polar regions and lower latitudes, to better understand these fluxes' role in global oceanic and atmospheric circulation. For example, water masses formed at the poles drive the north-south circulation of the world's oceans. At the margins of Antarctica, freezing ice expels salt and the resulting cold, salty, dense water sinks to the bottom where it spreads out and moves northward. In the Arctic, dense water sinks to intermediate levels and spreads southward. POLES is quantifying such ocean mixing and horizontal transport.

When POLES began in 1989, polar researchers used primarily climatological data from the central Arctic and simple model parameterizations, which precluded simulations of regional or interannual variability. To encourage the use of satellite observations, POLES is developing, assessing, and improving satellite algorithms, producing multidecadal data sets, and modeling polar processes in a combined atmosphere-ice-ocean system. To better relate satellite measurements to physical phenomena, POLES is developing algorithms for visible and thermal sensors (to distinguish clouds in the atmosphere from ice or snow at the earth's surface) and for microwave and synthetic aperture radar signals (to improve the interpretation of climatic quantities, such as snow cover and the onset of surface melt and freeze-up).



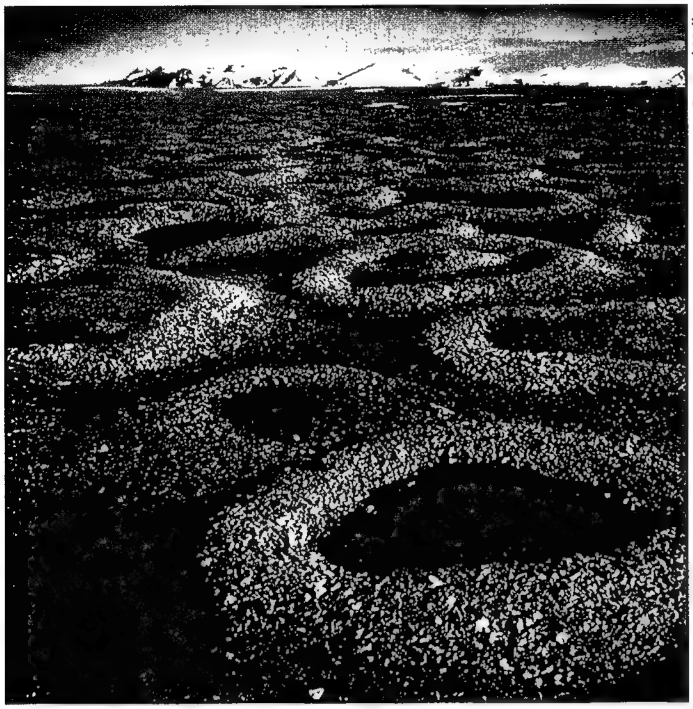
A comparison of synthetic aperture radar imagery in the Greenland Sea (a and b), with a computer model (c) of the ocean surface structure during deep convection. (b) is a blowup of (a) and is at the same scale as (c). Such comparisons lead to refinements of models and improvements in satellite algorithms. (Graphic courtesy of F. Carsey)

Specialists in different types of satellite sensors, drawn together by POLES, are creating a more comprehensive view of the polar climate while addressing the weaknesses and capitalizing on the strengths of polar satellite data. For example, using the TIROS Operational Vertical Sounder (TOVS) and Advanced Very High Resolution Radiometer (AVHRR) sensors, POLES scientists have accounted for the bright cold surface underlying clouds and retrieved useful estimates of cloud and surface properties. Models and algorithms have been combined into an integrated program and toolkit called the Cloud and Surface Parameter Retrieval (CASPR) system. Synthetic aperture radar sensors are being used to develop ice-tracking techniques to provide ice-motion data.

Large-scale, long-term POLES data sets will provide baseline standards for polar variables for process studies and model development. The data include radiative and turbulent surface heat fluxes, cloud properties, surface temperature and albedo, sea-ice concentration and thickness distribution, ice melt and growth, and surface brine flux. Sea-ice motion data have been assembled using historic data from buoys and drifting ice stations. Data from the 1992 Lead Experiment are being incorporated to test satellite-based estimates of surface radiative and turbulent fluxes. The upcoming Surface Heat Balance of the Arctic (SHEBA) field experiment, scheduled to begin in 1997, will provide data on cloud cover and radiative properties.

Co-investigators from the University of Colorado, the Jet Propulsion Laboratory, and Rutgers University, as well as from the UW School of Oceanography and Department of Atmospheric Sciences, have joined with the Applied Physics Laboratory in this multiyear effort. POLES, now in its sixth year, is scheduled to continue until 1998.

Liquids Below the Freezing Point: The Phenomenon of Surface Melting



Bernard Hallet

Frost-heave circles on Spitzbergen Island. This geophysical phenomenon results from the migration of thin films of water along a temperature gradient. Geometric patterns of rocks, soil, and ice develop in water-saturated arctic and alpine soils where the temperature fluctuates about the freezing point. Patterned ground is a particularly striking result of soil motion due to freezing and thawing, termed "cryoturbation."

It's hard to imagine Oksana Baiul, the 1994 Winter Olympic gold medal winner in women's figure skating, executing her smooth and stunning bladework on cement. Yet, without the effects of friction, and a phenomenon known as surface melting, that is very much how ice skating would feel.

During the surface melting of ice, a thin film of water at the ice/air interface acts as a lubricant that assists the smooth motion of the blade. This film exists as a liquid even at temperatures well below the freezing point of water. Understanding this phenomenon has fundamental consequences and broad applications in engineering, as well as in biological and environmental science and industry. Pursuing the research that will provide the answers is APL Physicist John Wettlaufer, a scientist in the Polar Science Center.

Recent advances in condensed matter physics have shown that surface melting occurs in many classes of solids—metals, semiconductors, solid rare gases, and molecular solids. Wettlaufer, not surprisingly, considering the focus of the Polar Science Center, has chosen to study surface melting in ice. The physical principles involved are relevant to other substances of interest in materials processing, metallurgy, and solid state electronics.

While it is well known that the three phases of water (ice, liquid, and vapor) can coexist in equilibrium with one another at the freezing point, Wettlaufer's interest is in the processes at the boundaries of the different phases. Here two- and three-dimensionality blend and molecules are distorted relative to those inside the bulk materials, or phases. For example, if one considers the density differences between ice, water, and water vapor, it isn't hard to imagine that a water molecule at the solid-vapor interface possesses a different energy than one at the solid-liquid interface. Nature favors the most energy-efficient configuration, and, in the case of surface melting, replacing the solid-vapor interface with a solid-liquid plus a liquid-vapor interface is the least costly, even at temperatures well below freezing.

While ice skating is a familiar application of the phenomenon, there are many other consequences of the behavior of these so-called interfacial thin films, the boundaries between the phases of matter. One widely experienced environmental effect, frost heaving, causes potholes. To replicate a frost-heave type of deformation at the microscopic level in the laboratory, Wettlaufer has blended his theoretical work with that of experimentalist colleagues J. G. Dash, Professor Emeritus in the UW Department of Physics and APL Adjunct Principal Physicist, and L. Wilen, Research Associate in Physics. Their work corroborates the theory that the migration of unfrozen, or subfreezing, thin films of water along a temperature gradient, i.e., from at depth in the ground toward the surface, results in frost heaving.

Understanding the behavior of thin films and interfacial melting may lead to better understanding of related phenomena. In biology, mitigating the damaging effects of freezing on human tissue samples is one possible outcome. Thin film research may also shed light on the formation of thunderstorms. While many aspects are well understood, the mechanism that generates the charging remains a mystery. The answer may be that a transfer of electrical charges between ice particles in the atmosphere occurs when the thin films of water coating each ice surface come into contact with each other.

There are also industrial applications of thin film phenomena. For example, inkjet printer quality depends on turning a tiny droplet of ink into a thin film coating a dot-shaped spot on paper. The dots combine to form a letter if the ink remains stable and does not splatter. Wettlaufer's colleague J. G. Dash has applied the scientific principles of interfacial melting and thin films to an "ice sweeper" that can help sweep soils clean of pollutants. This technology is being evaluated for cleaning up nuclear waste sites.

Submarine Research Cruise Under the Arctic Ice

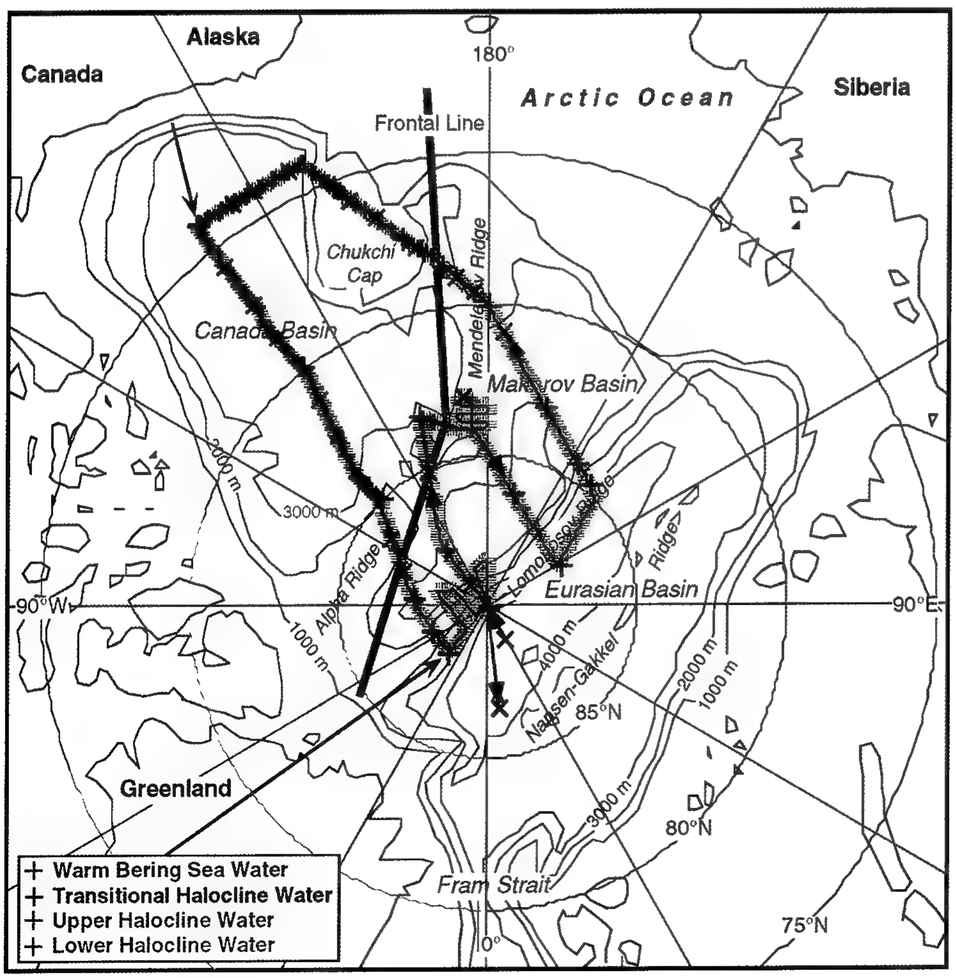
Two APL scientists participated in an historic submarine research cruise under the Arctic ice in the summer of 1993. The cruise marked the first time a first-line Navy submarine was used exclusively to support nonmilitary research projects for such an extended period. Long a dream of Arctic scientists frustrated by lack of access to remote areas of the region, the cruise was possible because of the end of the Cold War.

Principal Oceanographer Jamie Morison and Principal Research Scientist Roger Colony, both of APL's Polar Science Center, participated in this groundbreaking event. They joined three scientists from other academic institutions on board the USS *Pargo*, a *Sturgeon*-class nuclear attack submarine, on August 11, 1993, in Groton, Connecticut.

The Scientific Ice Expedition-93 (SCICEX-93) covered 9080 km under the ice in 38 days and ended in Bergen, Norway, on September 18. The data collected will shed light on global climate change, the geological evolution of the Arctic Basin, movement and changes of the permanent ice pack, and the Arctic Ocean's biological and chemical environment.

Although the Arctic is familiar territory for APL, the submarine provided a new and valuable platform for data collection. Icebreakers have a long history of Arctic research, but move relatively slowly at 3 to 4 knots; weather and ice conditions can preclude reaching planned sampling stations. Camps on the drifting ice allow for long-term study, but ice trajectories are subject to the vagaries of wind and current. Moored meteorological buoys that collect data as they drift along with the ice pack suffer from the same lack of control. None of these traditional methods of Arctic field work can match the nuclear submarine's ability to travel quickly from spot to spot in the ocean under the permanent ice cover, or to return repeatedly to a given location.

The submarine's unique qualities particularly suited Colony's and Morison's data collection requirements. Morison, a physical oceanographer, had three objectives: first, to study the hydrography and circulation in the central Arctic, particularly in the Makarov Basin, where the oceanography is virtually unknown; second, to confirm previous studies that had



The cruise track of the USS Pargo, *August–September 1993. Locations of the expendable-conductivity-temperature-depth (XCTD) measurements taken when the vessel was under way are indicated by* (x), *while those taken by standard CTD instruments at surface stations are indicated by* (+). *Colors indicate water types. The frontal line indicates the boundary between Pacific- and Atlantic-dominated ocean conditions.*

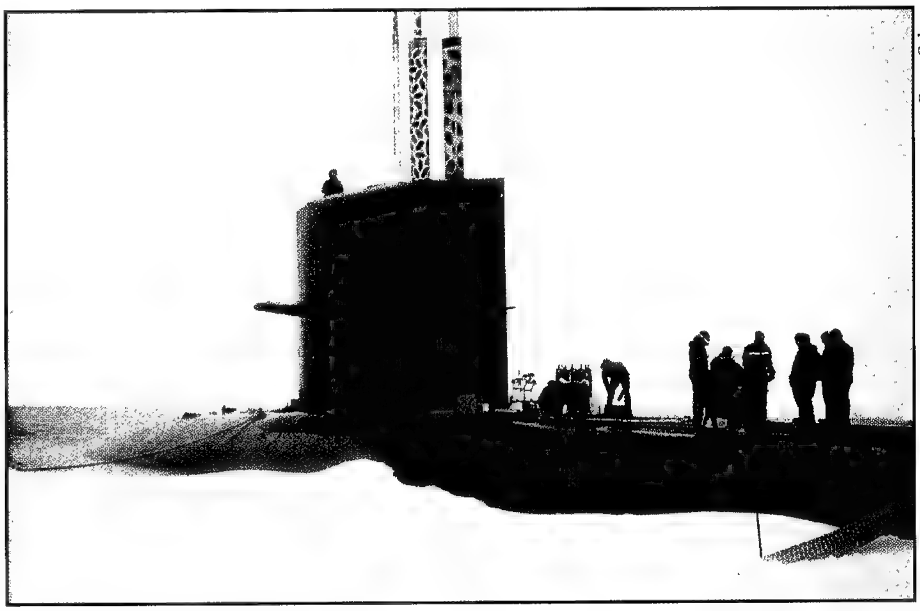
found mixing of the surface waters due to internal waves to be very low except in regions over topographic features such as ridges; and third, to determine the frequency of the occurrence of mesoscale structures such as fronts and eddies.

Colony, who also serves as coordinator of the International Arctic Buoy Program, was principally interested in the large-scale variability of ice thickness and the amount of ice cover. Ice thickness data were collected with an acoustic ice-profiling system that measures the distance to the bottom of the ice. The submarine's ability to return and resurvey the precise track followed during earlier cruises, regardless of surface conditions, is a major advantage for ice observations: a systematic study can be made of changing ice conditions, and year-to-year changes can be monitored.

One of the reasons U.S. submarines have such an enviable safety record is that modifications to the submarine, however simple they may seem, are scrutinized very carefully to understand any possible impact they may have on safety or operations of the vessel. The very short lead time for preparation could have been disastrous for the scientific program had it not been for the expertise and background of APL engineer Chris May. May, a submarine-qualified commander in the Naval Reserve and an associate of Morison's, was instrumental in the design and installation of a variety of oceanographic sensors. These included a sail-mounted instrument to continuously measure conductivity and temperature while underway and a winch and platform for hydrographic measurements when surfaced. With onboard space at a premium, special cases for oceanographic buoys were designed that allowed storage amidst the submarine's torpedoes. Access topside on a submarine is limited to a relatively small hatch, through which all equipment must be manhandled. The vessel surfaced for 20 sampling stations, and May's innovative equipment designs were major factors in their success.


Roger Colony

The APL-designed and fabricated two-person platform, complete with electric winch and boom, that was hung over the side of the submarine to make conductivity, temperature, and depth measurements.


Roger Colony

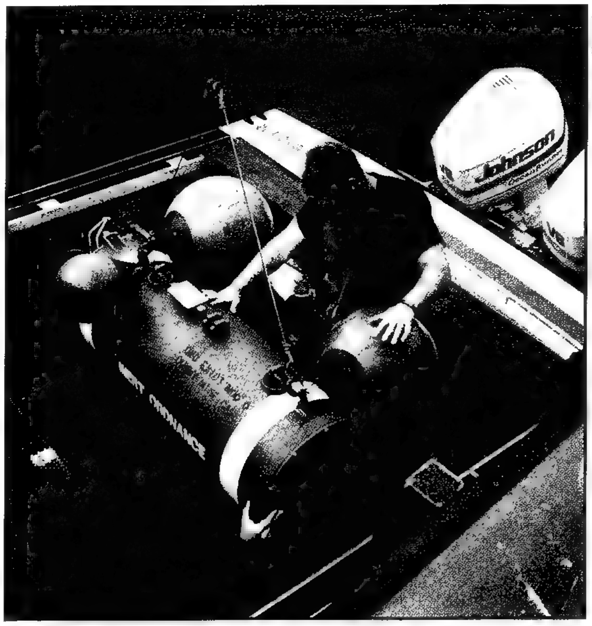
The USS Pargo *on a surface station in the Arctic.*

Both Morison and Colony have high praise for the well-qualified and cooperative crew members on board the *Pargo* who lent a hand with the scientific operations at every stage. The crew's interest and enthusiasm for the work were important contributions to the mission's success.

Data collection was sponsored by the National Science Foundation. A second submarine research cruise with APL participation took place in the spring of 1995. Scientists are hopeful that this Navy/civilian collaboration will continue for many years.

Improved Training for Navy Explosive Ordnance Disposal Divers

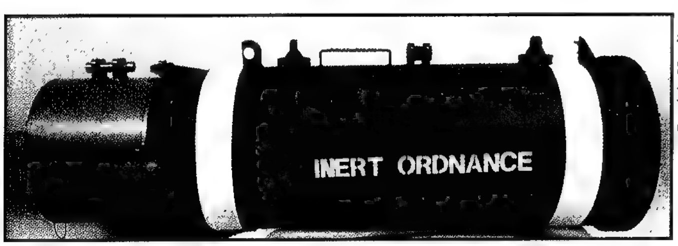
Anyone who remembers the PBS Masterpiece Theater series "Danger: UXB" has a good appreciation of the perils of disarming ordnance. Imagine performing those very sensitive operations underwater, in poor visibility, and you have an idea of the problems faced by the Navy's Explosive Ordnance Disposal (EOD) divers.



Russell Light

The Diver Evaluation Unit (DEU) mine case is lowered from the dock into an Explosive Ordnance Disposal (EOD) mobile unit boat in preparation for deployment.

The sea mine, one of the simplest and most effective weapons in the military arsenal today, is designed to deny access to ships and landing craft. The task of clearing these mines often falls to EOD teams. The lives of these Navy divers depend on the training they have received, and on their knowledge of how a mine works and how to avoid detonating it. Practice is an essential part of training, but how does one practice disarming mines? This problem sent the Commander of EOD Mobile Unit Three, based in Coronado, California, to the Navy Science Assistance Program (NSAP) seeking help. Through NSAP, APL was tasked to find a solution.



Patricia Hardisty

The DEU instrument case is shown attached to the mine case.

Underwater mines are designed to be sensitive to a variety of influences, including those generated by a passing ship: the pressure wave, the magnetic signature of the hull, contact or motion, and the sound emitted. Divers, too, can generate these influences and cause the mine to explode if its sensor thresholds are exceeded. Therefore, learning what constitutes safe behavior near a mine is an essential part of training. This is the function of the APL-designed Diver Evaluation Unit (DEU): It provides divers with immediate feedback on the safety of their actions as they practice on a mock mine.

Real mines can weigh up to 1000 lbs or more, yet for training purposes the Navy needed something that could be easily deployed from the small, rigid-rubber, inflatable boats used by EOD teams. APL's solution was to build the DEU in two modules—a sand-filled mine case that is left on the bottom, and a detachable instrument package that is attached to the case by the divers for training sessions.

The instrument package consists of a computer-controlled suite of sensors, processing electronics, solid-state memory, and batteries in a pressure case. The DEU incorporates or emulates actual mine sensors for sound, magnetism, and case motion. A pressure sensor was not included because pressure-activated mines are designed to be triggered by the pressure wave produced by the hull of a ship, and the pressure signature generated by a diver is too small to detonate a mine.

The DEU provides immediate feedback when the diver exceeds a preset sensitivity threshold: An alarm that can be heard underwater is triggered. One beep signals the diver that he has exceeded the threshold of the seismic sensor; two beeps, the acoustic; and three, the magnetic. For example, if a diver pauses to clear his mask and is within three feet of the DEU, two beeps would let the diver know that his action was potentially dangerous because it could have exceeded the acoustic threshold of the sensor in a real mine. The alarm can be disabled for blind testing.

Throughout the training exercise, the DEU continuously records sensor activity. This information is downloaded into a computer during post-dive analysis and is available in both graphical and tabular form. By comparing the dive log to the DEU data record at the corresponding time, the diver is able to determine which of his actions approached or exceeded the thresholds. Thresholds can be set at any level, depending on the competence of the diver. The DEU is a first in diver training and should significantly enhance the training procedure.

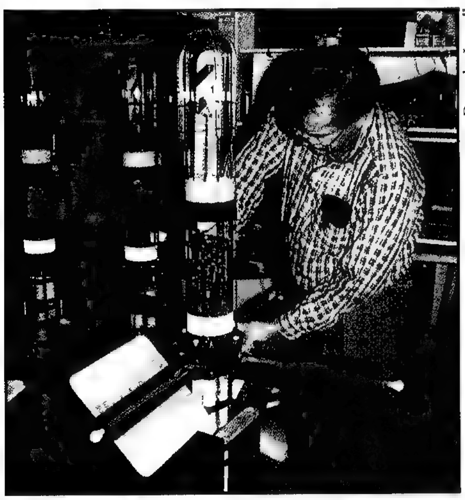
Although complex in design, the DEU was engineered to be user friendly. The engineering team, led by Ocean Engineering Department Head John Hart, has a long history of designing and building successful underwater instrumentation. The project's mechanical engineer, Senior Engineer Mike Welch, a diver himself, understands well how to build equipment that divers will use. Senior Engineer Russell Light served as the electrical and systems engineer, while Engineer John Elliott designed the software.

In the spring of 1994, two DEU development models were shipped to EOD mobile units in Hawaii and Virginia for evaluation by fleet personnel.

The Electric Field Float

A new instrument that measures ocean transport has been developed by APL Principal Oceanographer Tom Sanford and his associates. The Electric Field Float (EFF) operates over a wide area for long periods of time and is the latest in a series of APL-developed instruments that use electromagnetic sensors.

Barotropic, or depth-averaged, currents such as tides, while generally slow, are important because they transport large amounts of water. From a global climate change perspective, they transfer heat introduced at the ocean surface to other locations and depths. The net effect is that the oceans serve as a heat buffer, smoothing out short-term atmospheric changes. A better understanding of this heat transport mechanism is necessary to predict global climate change accurately.



Dorothy Lowell

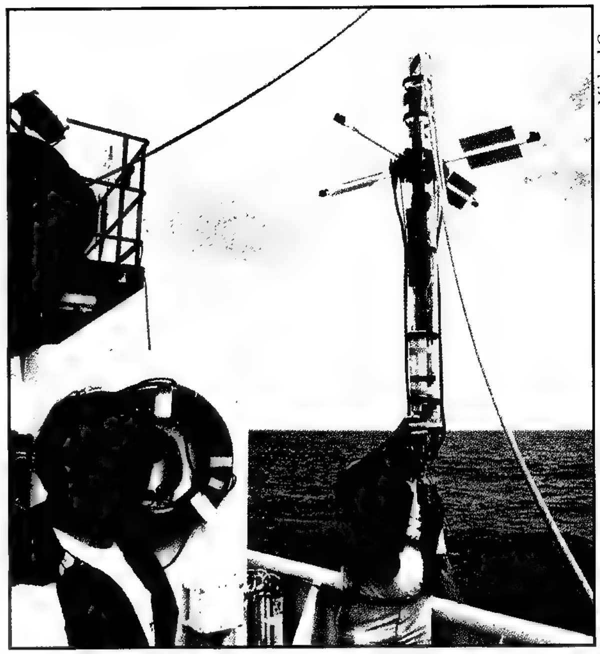
Bob Drever building an Electric Field Float in the APL Oceanography Lab.

Because of the large area to be covered, conventional means of measuring barotropic currents are very expensive. Long vertical strings of current meters would have to be moored to the bottom in many places to make the desired measurements. In addition to the prohibitive cost of the instruments, setting and recovering the strings would require many days of ship time. With research budgets shrinking, a more cost-effective data-collection method, such as the EFF, is preferred.

The EFF is an electrical field sensor installed in a commercially available, neutrally buoyant RAFOS float consisting of a weighted glass tube containing sensors and electronics. Because the tube is less compressible than water, the float sinks to a level determined by the ballast weight, where it drifts with the prevailing currents. By using an onboard acoustic location system to observe the path of the float, scientists can compute net water motion at that depth.

The EFF uses sensors that measure the electric field potential induced by the float's motion as it passes through the vertical component of the earth's magnetic field. The velocity of this electric field is computed by measuring the potential between horizontal points 1 m apart and dividing by the vertical component of the earth's magnetic field. Subtracting the velocity of the float from the electric field velocity yields an estimate of the vertically averaged velocity of the current.

The electric field sensors consist of an orthogonal set of horizontal seawater-filled tubes with electrodes mounted on their inboard tips. Also mounted on the tubes are large vanes set at 45° to induce float rotation as it responds to the relative vertical velocity of internal waves, a technique used to mitigate electrode drift. The instrument also carries a compass and sensors to measure pressure and temperature. Data are recorded internally until the end of the mission, at which time the ballast weight is released, the float surfaces, and the data are transmitted to shore via a satellite link. Typical missions are one or two months long, although yearlong deployments are anticipated. The floats are not usually recovered, yet even so the EFF is highly cost effective because relatively few instruments, compared to conventional current meters, are required, and because expensive ship time is minimized.



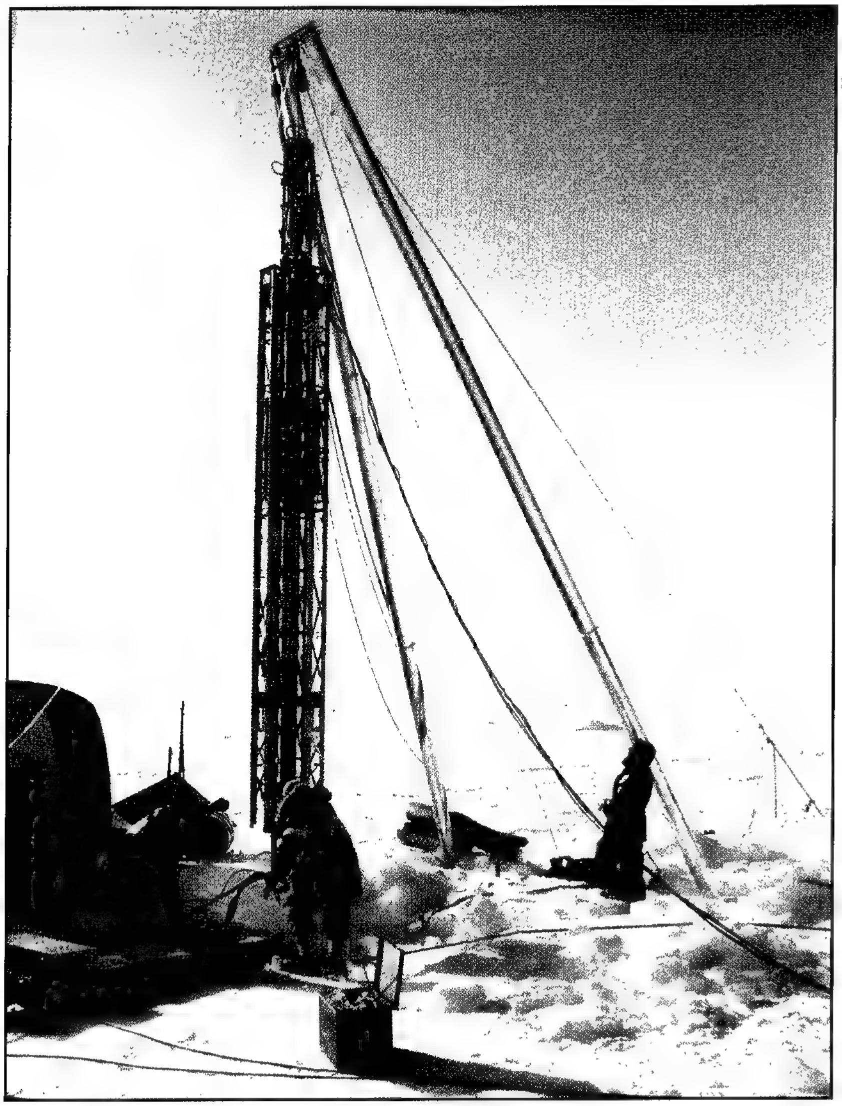
Michael Gregg

Jim Carlson (left) and Bob Drever (right) prepare to launch an Electric Field Float from the R/V Moana Wave *in the equatorial Pacific Ocean.*

To date, two deployments have been made. Two EFFs were launched off Northern California in the California Current system for a 30-day mission in March 1994, and five EFFs were launched in late 1994 in the more energetic Gulf Stream and North Atlantic Current off the Grand Banks for a 60-day period. These test deployments demonstrated the capabilities of the floats while also providing engineering data for design improvements. The instruments functioned well, but it was discovered that a higher antenna was required for satellite transmissions to avoid data dropouts in rough seas.

Sanford and his team are moving ahead with plans to provide a similar electric field current-measuring capability to the ALACE float. Developed at the Scripps Institution of Oceanography, ALACE has the ability to adjust its ballast and make as many as 60 vertical excursions through the water column in a single mission. Whereas the EFF completes its mission after reporting its data, an ALACE float is capable of rising to the surface to report data periodically, and then descending. Repeated cycles provide more timely data and offer longer total observational periods.

Multipurpose Acoustic Instrumentation



Terry Ewart

Installation of the IBEX main array through the ice.

Acoustic instrumentation designed for widely varying environments has proven its worth in two recent experiments—one in the waters of the North Pacific, the other under the ice in the Arctic.

The teams that designed and built the instrumentation were led by Principal Physicist Terry Ewart of APL's Ocean Physics Department, Senior Physicist Kevin Williams, Principal Physicist Eric Thorsos, and Principal Engineer Le Olson. Dubbed "acoustic Legos" for the versatility with which the components can be assembled, the equipment is designed to measure the scattering of underwater sound using a system of acoustic transducers and electronics mounted in a collapsible frame. The components are linked together through a computer network; changing parts and functions may be as simple as changing a line in a computer program.

The instrumentation was first deployed in February 1993, during the Cascadia Basin Experiment (CABEX), in the open ocean about 70 miles west of the southern tip of Vancouver Island. Jointly funded by the Institute of Ocean Studies (IOS) in British Columbia and the U.S. Office of Naval Research (ONR), CABEX made acoustic backscatter measurements simultaneously with near-surface bubble structure observations under a variety of wave conditions. Principal Investigators on the CABEX scientific team were Ewart, Thorsos, and Principal Physicist Frank Henyey. David Farmer was the IOS Principal Investigator.

Conducted from the Canadian R/V *Tully*, CABEX demonstrated the soundness of the instrumentation concept. Barely a year later, in the Ice Backscattering Experiment (IBEX), the modified equipment was reassembled and deployed under the Arctic ice to characterize backscattering of sound from the bottom of the ice pack. Senior Engineer Vern Miller headed the IBEX engineering team that included Oceanographer Mike Kenney and Senior Engineer Dave Van Ess. Senior Oceanographer Steve Reynolds is analyzing the data. Ewart and Williams are the Principal Investigators.

The CABEX/IBEX arrays have their genesis in the "pencil-beam" acoustic array developed by Ewart and Thorsos in the late 1980s. Unlike the pencil-beam array, however, the CABEX/IBEX arrays transmit from several low-frequency sources and receive on a widely spaced suite of hydrophones. In experiments characterizing sound scattering in the natural environment, the multiple sources ensure accurate characterization of scattering conditions in the precise area covered by transmitted/received sound beams. Although the CABEX/IBEX arrays use pencil-beam components, the transmitters and receivers are distributed throughout the array. An image is formed by combining the records from all of the transmitters and receivers. This produces a more complete picture than was previously available using traditional beamforming techniques.

IBEX is a part of ONR's Sea Ice Mechanics Initiative. In March 1994, the IBEX field team set up a camp on the drifting ice pack 200 miles north of Deadhorse, Alaska. Despite the harsh conditions, the pack ice provided a stable platform from which to stage the experiment, while eliminating the time-variable returns from sea surface scattering. The carefully controlled observations of backscattering from the ice could then be com-

pared with confidence to independent measurements of the ice structure made by ice mechanics investigators. The array also imaged sound backscattered from an ice keel, a deep protrusion of ice below the pack.

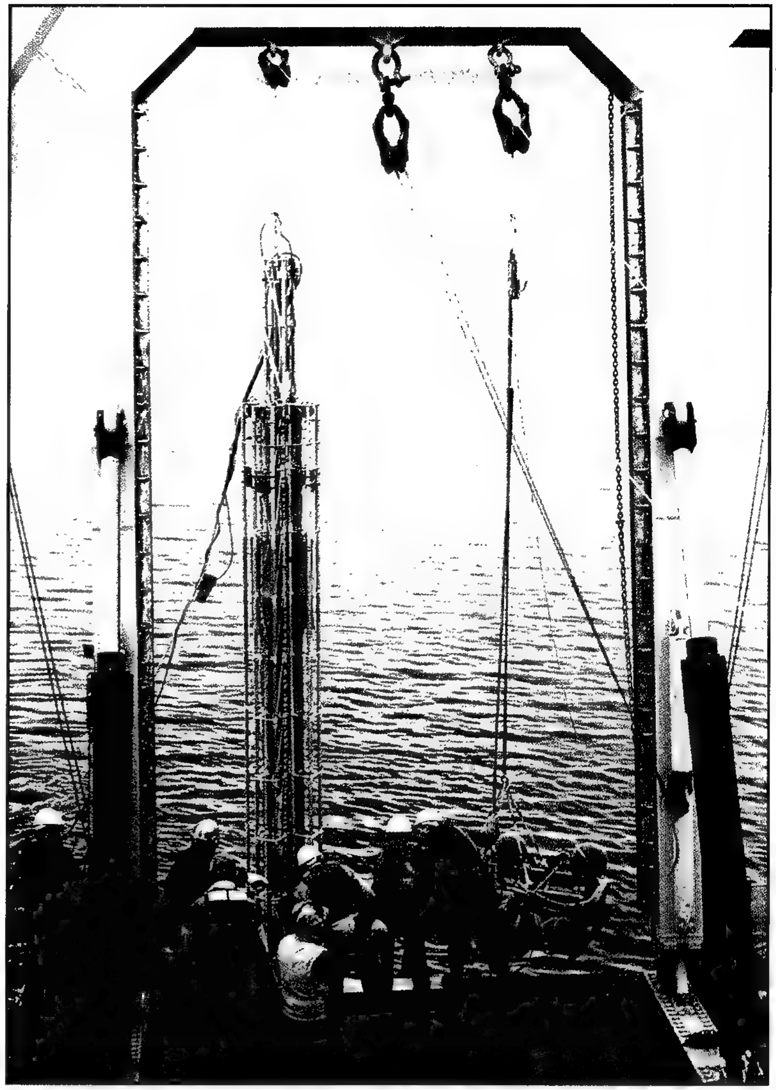
The scientific and engineering creativity responsible for the design of the "acoustic Legos" measurement system resides in the Multiple Discipline Group (MDG), a group of oceanographers,

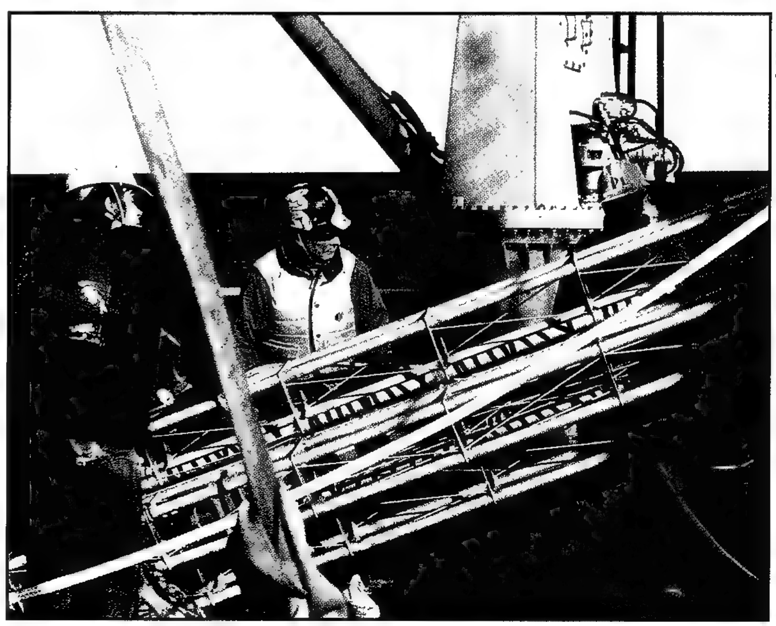

Frank Henyey

David Farmer and Terry Ewart aboard the R/V Tully.

physicists, acousticians, electrical engineers, and mechanical engineers working together on ocean acoustics problems. Members of the MDG come from departments at APL and the University of Washington (UW), and frequently collaborate with colleagues in Canada and England. Ewart, who is also a Professor of Oceanography, is the MDG founder and current Chair. The expertise available through this group allows APL to take on complex acoustic problems, such as surface zone backscattering and bottom scattering, that have both theoretical and experimental components.

For IBEX, the MDG's work was directed toward the processes that affect acoustic propagation beneath the ice canopy and toward understanding how acoustic energy is backscattered from the rough underside of the ice. Ewart expects high-quality results owing to the high quality of the IBEX data, which are now being processed. The experiment's imaging techniques could have far-reaching applications, including the refinement of algorithms used in underwater mine detection.


Frank Henyey


Frank Henyey

Deployment of the CABEX main array in Canadian waters.

Finding the Patterns in Acoustic Surveys of Fish

A new tool for scientific surveys of fish populations, based on acoustic survey techniques, is under development at APL. Gordon Swartzman, APL Senior Engineer and Research Professor of Fisheries, and colleagues are developing computer data-analysis methods for automatic identification of species.

Acoustic survey techniques replace the old method of trawling with nets, a labor-intensive operation where captured fish are identified and counted. The trawls provide only spotty geographic coverage and destroy some of the very resource being studied. Acoustic surveys, by contrast, provide much wider geographic coverage in less time, offer increased accuracy, and require fewer people. Because acoustic surveys do not interfere with normal ship operations, they can be undertaken from a wide variety of ships, thereby increasing the number of surveys possible. Specially designed downward-looking sonars transmit signals that reflect from fish and other objects in the sound beam. Gas-filled fish swimbladders produce particularly strong echoes that indicate the presence and type of fish. While many fishermen and survey teams claim they can identify fish species based on a sonar echogram, such identifications are, in fact, subjective and often inaccurate: They depend on the observer's skill and experience (and often with a bit of magic guessing thrown in).

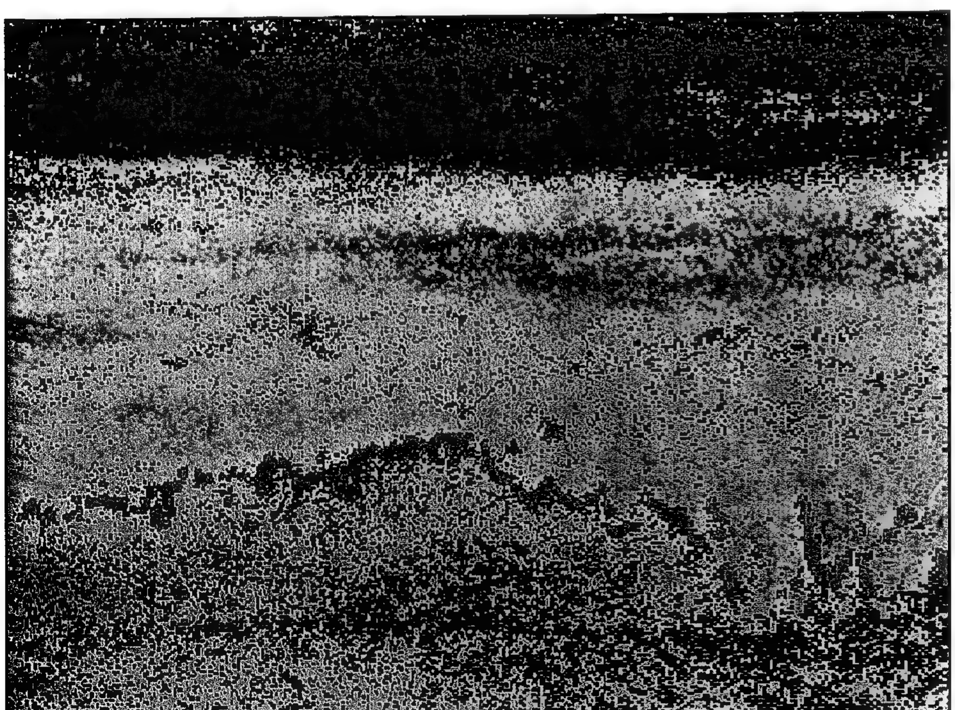
Swartzman recognized that making the best use of the voluminous data sets acquired by acoustic surveys requires an objective method of interpreting the sonar data. Ideally, one would trawl the same fish being sampled by the sound beam so that the echoes could be correlated with the actual catch. Then, when similar echoes are encountered, the presence of that species is inferred. The remaining step is to program a computer to do the classification automatically.

Because such ideal sea-truth observations are sparse, Swartzman spent three weeks in the summer of 1994 on a survey ship in the Bering Sea collecting both acoustic and trawl data. Back in the Laboratory, he explored the character of the acoustic signals for clues that might be generalized to other data sets. Using this information, he and his colleagues have developed an algorithm that takes advantage of pattern shapes in the data to identify types of fish. Information about the depth at which schools occur and the size of the schools is also extracted. Their approach uses a type of image processing called morphological processing, which is based on earlier work at APL to detect mines in visual images of shallow water.

One of the goals of Swartzman's project is to understand the conditions that lead to fish school formation—what makes fish form schools and is it related to environmental factors such as depth and temperature? Do certain types of fish have a particular depth preference? As an example, by combining acoustic survey data from the Bering Sea with data on water temperature, Swartzman discovered that pollock congregate along ocean fronts where nutrients are concentrated. The locations of such areas may be common knowledge to fishing boat operators familiar with the area, but when boats move into less familiar waters, understanding where and why species of fish occur can spell the difference between making and losing money on a trip.

Analysis of the acoustic data and comparison with the trawl data will lead to a representative model, Swartzman believes. He is particularly excited by the fact that his method may result in efficient processing of voluminous amounts of information collected from wide and diverse geographic areas. This will provide the "wide angle" view that is much more valuable for fisheries management than the single "snapshot" that trawl sampling provides.

Sponsored by Washington Sea Grant, Swartzman has been working with data collected by the U.S. Navy and by the National Marine Fisheries Service. He has focused his work on fish in the Bering Sea and off the U.S. west coast, particularly pollock and hake.



Distinctive acoustic patterns, as shown here in pink in the lower half of the illustration, can be used to identify species of fish. In this illustration from the Pacific Eastern Boundary Current, the patterns are indicative of Pacific hake.

APL Synthetic Ocean Improves Torpedo Defense

Acoustic simulation technology has been an important part of APL's work for the Navy for many years, capitalizing on the Laboratory's expertise in ocean acoustics and software development, and familiarity with Navy systems and missions. A recent simulation development at APL is the Detection, Classification, and Localization Acoustic Signal Processor (DCLASP), part of a program to enhance the Navy's defensive capabilities against torpedoes.

The Navy uses simulations to control the costs of new-system development and existing-system upgrades. A recent mandate requires that the performance of a new system must be demonstrated through simulation before moving into the acquisition phase. This "virtual prototyping" requires computer models of the system itself and of the ocean in which it operates. In the case of DCLASP, APL is developing the synthetic ocean that the Naval Undersea Warfare Center (NUWC) in New London, Connecticut, will combine with torpedo defense system models to predict the performance of candidate torpedo defense systems.

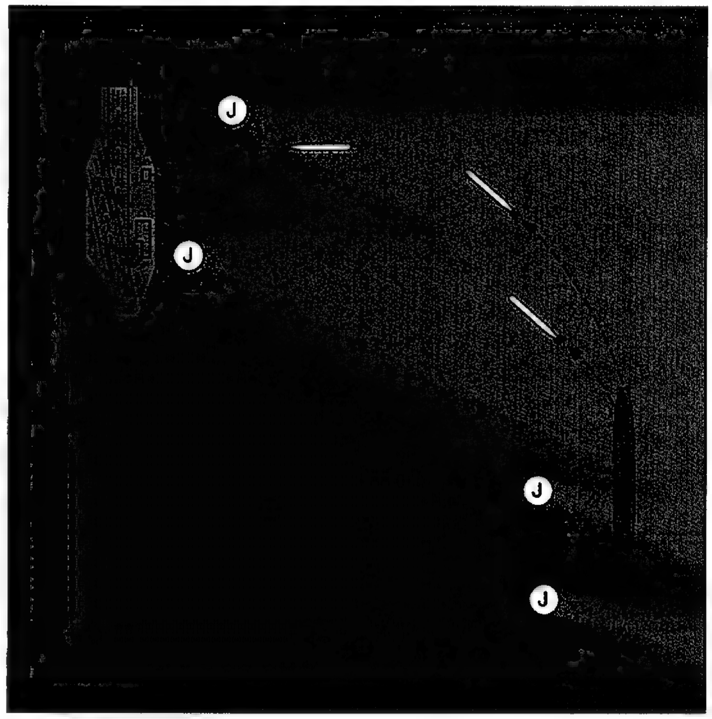
Under the direction of SSP Department Head James Luby, DCLASP is representative of the many Laboratory projects that draw upon APL's expertise in acoustic research and then transfer the results to applied Navy systems. In DCLASP, this expertise is applied to modeling the acoustically complex shallow-water regions that are of tactical interest today. The result is a high-fidelity model, based on the physics of acoustic propagation, that can be used to design better systems to defend high-value assets such as aircraft carriers against torpedo attack.

Torpedo defense involves three primary phases: detection, classification, and localization (DCL). In the detection phase, acoustic sensors on board the defending ship continuously "listen" for the sounds associated with threat submarines. Once detected, a received sound is classified to determine whether it is associated with an incoming torpedo. If a threat torpedo is identified, the defending ship attempts to localize it and take defensive action.

In practice, the DCL process is fraught with difficulties. For example, in the detection and classification phases of real torpedo-defense scenarios, the system must detect and sort through sounds that are emitted from multiple sources, such as other surface ships, submarines, and marine animals. The localization phase is complicated by the fact that torpedo sounds arrive at the defending ship's sensors over a multitude of paths in the ocean.

To achieve the goal of making DCLASP an easy-to-use simulation, a graphical interface was developed to allow the user to specify the trajectories of the vehicles (submarines, surface ships, and torpedoes) in the simulation using the computer mouse and a set of trajectory drawing tools. Users may also specify the location (latitude, longitude) and time of year of the simulation run. With these inputs, all other environmental and vehicle parameters needed to completely specify the simulation run are automatically retrieved from Navy standard databases. For example, once the latitude and longitude are given, the Navy standard DBDB5 database is accessed to obtain the bathymetric profile of the ocean bottom in that area. The bathymetry information is needed in order to run the range-dependent propagation codes that are required to model shallow-water propagation accurately. Likewise, once a vehicle type is chosen (e.g., a specific type of enemy submarine), the simulation accesses the Navy Common Acoustic Data Base (CADB) to determine the radiated acoustic noise characteristics for that type of vessel when operating at the specified depth and speed.

Simulation is a rapidly growing methodology used to control the cost of new-system development. It is finding its way into virtually every Navy activity from aircraft to submarine design, and even into battlefield-tactics analysis.



Torpedo defense scenario. Aircraft carrier towing acoustic sensors (left) is taking defensive action against torpedoes launched from a threat submarine (right). **J** *indicates acoustic jammers deployed by the threat and carrier platform to confuse each other's systems.*

Education

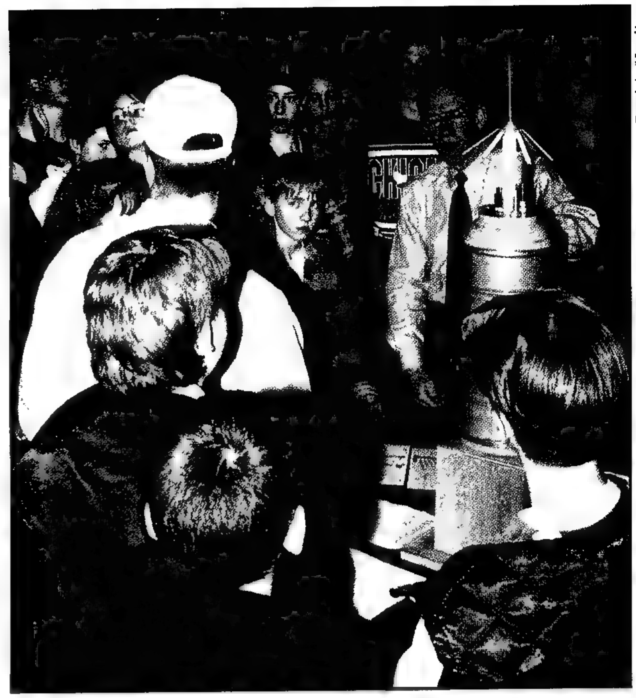
Since the inclusion of the Applied Physics Laboratory in the College of Ocean and Fishery Sciences in the early 1980s, APL has expanded its academic role through teaching and support of graduate student research. At the end of the 1993–94 academic year, there were 45 graduate students engaged in research projects at APL, all under supervision of APL staff who hold faculty appointments. The students are matriculated in ten academic departments, with the largest numbers in Oceanography and Electrical Engineering. Working alongside professionals in the role of junior scientist or engineer, these students gain diverse, practical experience and an appreciation for the role of research in maintaining the nation's technology base.

The Laboratory encourages qualified staff to seek faculty appointments, which are required for supervision of graduate students. Twenty-six APL staff hold faculty appointments and many also teach regularly.

To encourage participation of graduate students in APL research projects, the Laboratory offers fully paid fellowships for up to six students per year. This policy allows start-up support for the student while the principal investigator seeks independent funding from the project sponsor. The Office of Naval Research sponsors a program designed to promote joint research between APL and an academic unit at the University. The program requires the participation of a graduate student or a postdoctoral researcher and has been successful in establishing continuing collaborations with other UW departments.

The Applied Physics Laboratory recognizes the importance of the region's K-12 education programs and supports several initiatives with discretionary funds. After a successful start in 1992, the Laboratory continued its Summer Fellowship Program for High School Science and Math Teachers. Designed to give teachers a feeling for the research process by integrating them into an active project, the program supports two teachers for approximately ten weeks during the summer.

Other K–12 education programs include the Technology in Education Program, administered from the Pacific Science Center, which brings teachers to the Laboratory annually to enrich their teaching background through exposure to research projects. The University's Upward Bound program students visit APL to learn firsthand about science and engineering, knowledge which will help them make career choices. Math Day is an annual event at the University where APL and various other departments offer programs describing some of the many ways mathematics affects our lives. The Laboratory also supports the volunteer participation of staff members in primary and secondary school classrooms.


Patricia Hardisty

Deputy Director John Harlett demonstrates the Deep Lagrangian Float to high-school students visiting APL as part of the UW Math Day.

Advanced Degrees Awarded to APL Students & Staff

Azmi Al-Kurd, Ph.D., 1992	*Miro Powojowski, M.S., 1994*
Kate Bader, M.S., 1993	*Larry Rystrom, Ph.D., 1994*
Tamre Cardoso, M.S., 1994	*Harvey Seim, Ph.D., 1993*
Kevin Fink, M.S., 1994	*Martin Siderius, M.S., 1992*
Warren Fox, Ph.D., 1994	*David Smith, M.S., 1994*
Jennifer Francis, Ph.D., 1994	*Paulette Struckman, M.S., 1994*
Peter Kaczkowski, Ph.D., 1994	*Jane Verrall, M.S., 1994*
Mike Mathewson, M.S., 1994	*Chris Walter, M.S., 1993*
Eric Nelson, M.S., 1993	*Richard West, Ph.D., 1994*
Craig Novel, M.S., 1993	*Denise Worthen, M.S., 1994*
Pauline Paik, M.S., 1994	*Chris Zappa, M.S., 1994*

APL graduate students, with their research topics and advisors, are as follows:

Lynn Ailes-Sengers	*Ice Surface Wave Scattering*	*D. Winebrenner*
John Allen	*Mass Transfer in Pulsating Bubbles*	*R. Roy*
Tony Beesley	*Arctic Climate Modeling*	*R. Moritz*
Keith Brainerd	*Upper Ocean Turbulence & Mixing*	*M. Gregg*
*Adam Calabrese**	*Cavitation from Diagnostic Ultrasound*	*R. Roy*
*Sean Cordry**	*Sonoluminescence*	*L. Crum*
Keith Curtis	*Acoustic Oceanography*	*B. Howe*
Geoffrey Dairiki	*Langmuir Circulation*	*E. D'Asaro*
Martin Dorn	*Fishing Fleet Modeling*	*G. Swartzman*
Raymond Finch	*Simulation of Stratified Flows*	*K. Winters*
Troy Gilliland	*Microelectronic Receiver Design*	*E. Belcher*
James Girton	*Oceanic EM Fields*	*T. Sanford*

Eric Hirst	*Resonant Instability of Internal Tides*	*T. Ewart*
Chris Jones	*Underwater Acoustics*	*P. Dahl*
Ian Joughin	*Ice Scattering Mechanisms*	*D. Winebrenner*
Jody Klymak	*Mixing & Hydraulics*	*M. Gregg*
Robert Leathers	*Deep Ocean Velocity & Vorticity*	*T. Sanford*
Chris May[†]	*Impacts of Urbanization on Small Streams*	*E. Welch (Civil Engineering)*
Garfield Mellema	*Biot Wave Measurements*	*T. Ewart*
John Moe	*Bottom Scattering*	*D. Jackson*
David Myers	*Current Meter Analysis of Data*	*E. D'Asaro*
Jean Nam	*Wave Propagation*	*R. Porter*
Miguel Nathwani	*Acoustic Propagation in Sediments*	*F. Henyey*
Minkyu Park	*Shallow Water Acoustic Propagation*	*R. Odom*
Robert Ruedisueli	*Corrosion in Marine Environments*	*C. Sandwith*
Roy Schiff	*Wave Breaking*	*A. Jessup*
*Jeffrey Schindall**	*Scattering from Bubble Clouds*	*R. Roy*
Celt Schira	*Source Localization*	*T. Ewart*
Martin Siderius	*Acoustic Propagation*	*R. Porter*
Fritz Stahr	*Deep Ocean Dynamics*	*T. Sanford*
James Turner	*Estuarine Mixing Processes*	*M. Gregg*
Jack Turnock	*Alternative Abundance Estimation*	*G. Swartzman*
Chris Walter	*Ocean Acoustic Tomography*	*J. Mercer*
David Winkel	*Mixing & Turbulence*	*M. Gregg*
Yanling Yu	*Arctic Surface Temperatures*	*D. Rothrock*
Chris Zappa	*Small-Scale Wave Breaking*	*A. Jessup*
Lisa Zurk	*Microwave Scattering in Snow*	*D. Winebrenner*

*matriculated at the University of Mississippi and doing graduate work *in absentia*
[†]APL Fellow

The graduate career of **Lisa Zurk** (doctoral candidate, Polar Science Center) reached a high point in spring 1995 when she was honored with the prestigious Young Scientist Award from the International Union of Radio Science (URSI). It is unusual for a graduate student to be selected for this honor, as the award is typically made to junior faculty or postdoctoral researchers. In addition to recognizing her high-caliber work, the award supported her participation in the May 1995 URSI Symposium on Electromagnetic Theory in St. Petersburg, Russia.

Zurk arrived at APL's Polar Science Center in 1991 with an M.S. in Electrical and Computer Engineering from Northeastern University and four years of corporate experience in biomedical research and development. She benefits from the hands-on experience she gained in industry and has found that her background in computers, which includes an undergraduate degree in computer science, is a valuable asset in today's computationally intensive research environment. Her dissertation research, electromagnetic wave propagation in random media with application to microwave scattering from snow, blends theory, experiment, and computation, in line with Zurk's belief that these are the three pillars of research.

Patricia Hardisty

Her dissertation work is supervised by Dale Winebrenner, APL Research Scientist and Research Associate Professor in Electrical Engineering, and Leung Tsang, Professor, UW Electrical Engineering Department. Her research employs Monte Carlo simulations of random, densely packed spheres to interpret microwave backscatter from snow-covered regions in terms of geophysically meaningful parameters. According to Winebrenner, "Lisa has been very active and productive both in fundamental work on scattering theory and in experimental synthetic aperture radar imaging of the ocean surface, with publications in each area. She works hard and with good spirit." Other work at APL has included collaborating with Bill Plant, APL Principal Research Scientist and Affiliate Professor in Atmospheric Sciences, on research related to comparing actual and simulated synthetic aperture radar imagery of ocean waves.

Zurk has enjoyed the fact that her work with both Winebrenner and Plant has been focusing on problems in global terms, including changes in global climate and how humans are interacting with the planet. She likes "dealing in real world studies, to pick up a handful of snow and touch it." She credits both Winebrenner and Plant with a "good physical sense," i.e., with a great capability to test the logic of the theoretical, such as an equation, against the real world.

Along with research, Zurk has a firm commitment to quality teaching, having held teaching assistant positions at three different universities and having taught adult evening courses in computer hardware and software for five years. With her strong combination of research, application, and teaching, Zurk is seeking a tenure-track faculty position in Electrical Engineering and plans to complete her degree in summer 1995.

Geoffrey Dairiki (doctoral candidate, Ocean Physics Department) went to sea in the wintertime to study the wind-driven ocean phenomenon called Langmuir circulation. What he got instead was an unusually calm patch of weather in the North Pacific where not a breath of wind stirred for the entire cruise. However, the situation was not as grim as it seemed: Dairiki assisted his advisor, APL Principal Oceanographer and Professor of Oceanography Eric D'Asaro, with the highly successful, first open-ocean test of an innovative new piece of equipment, the mixed layer float.

The data collected with the float during this calm period turned out to be a rich source of information about the transfer of heat from atmosphere to ocean and vice versa, factors that play a role in Langmuir circulation. And Dairiki was able to use the mixed layer float on other cruises to collect the data he is now using in his dissertation.

As Dairiki explains, Langmuir circulation often manifests itself at the surface of the ocean when floating grak (e.g., foam and seaweed) forms rows called windrows. These are the surface expressions of helical water motions that resemble very large jellyrolls laid side-by-side, their lengthwise axes roughly aligned with wind direction. Dairiki's research is focusing on the genesis and cause of this phenomenon, an important contributor to the mixing that occurs in the surface layers of the ocean. He is comparing the most common theoretical explanation, the Craik-Leibovich theory, with the observational data taken with the mixed layer float.

Eric D'Asaro

D'Asaro remarks that "because Geoff came here with a B.S. in Electrical Engineering from the California Institute of Technology, he has been able to build the instrumentation used for his Ph.D. project. It will take at least two people to replace Geoff's skills in my group after he graduates."

What's next for Dairiki when he finishes his degree in 1996? Research, most likely, where "you are constantly learning new things," he states. In the meantime, he keeps a lookout for windrows from the deck of his home, a 34-foot sailboat on Lake Union.

The Laboratory was the beneficiary of oil company downsizing when **Chris Walter** (doctoral candidate, Acoustics and Electromagnetics Department) left Tenneco in 1989 and entered graduate school. Although he had offers from other schools, Walter was attracted by what he calls APL's "appropriate mix" of team-oriented applied research in an academic environment. Of course, the chance to trade the steamy flatness of Houston for the cool, green mountains of the Pacific Northwest held a certain appeal as well. When APL Principal Physicist Jim Mercer offered him a role in the acoustic tomography project, the deal was clinched.

Patricia Hardisty

Mercer, who holds a faculty appointment in Geophysics and is Walter's advisor, describes this Ph.D. candidate as hard working, serious, and particularly adept at working with large-scale computing problems. Walter's background is in geophysics and he holds a B.S. degree in Geophysics from the Montana College of Mineral Science and Technology. He began at the Laboratory as an M.S. candidate, receiving that degree in 1993.

The transition from land-based oil company work to ocean studies was not always smooth: The ship almost left him at the dock on his first oceanographic cruise, and he once astounded Bob Spindel, APL's director, by admitting that he didn't know what the *Fram* was. Walter soon got his sea legs, however, and actually climbed on board the *Fram* (the first vessel designed to withstand the rigors of polar research) at the *Fram* museum in Oslo, Norway.

In 1991, Walter took part in the AMODE (Acoustic Mid-Ocean Dynamics Experiment) project in the Sargasso Sea, where he collected the data that he is now working on for his doctoral thesis. The goal of AMODE was to assess the precision with which acoustic tomography can be used to study ocean structure. Walter's work involves assimilating the AMODE acoustic data into an ocean circulation model.

As Walter explains, "A model is really just a set of differential equations evolving through time." His task is to integrate the observational data into the mathematical model in order to create a more complete picture of the structure of the ocean in the study area.

Finances

APL's financial condition was strong through Federal Fiscal Years (FFY) 1993 and 1994. Grant and contract awards, at $36.4M and $26.3M, were slightly in excess of expenditures. Navy project work accounted for about 70% of the total.

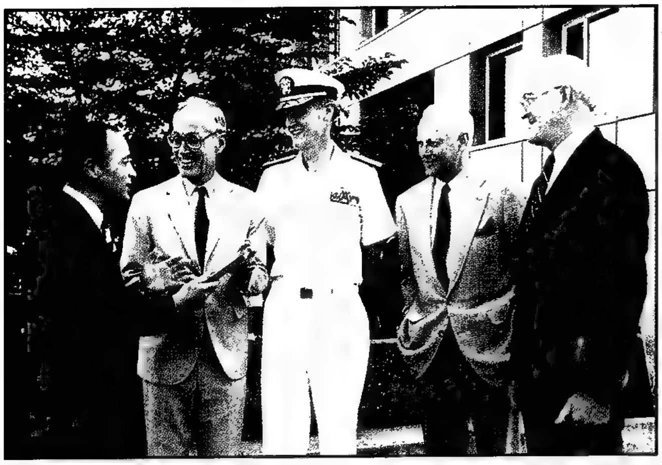
The Navy's budget was reduced in FFY 94 and FFY 95, and we expect this trend to continue over the next few fiscal years. Precisely what this means in the long term to a university research and development laboratory such as APL remains uncertain. Given that the Laboratory retains talented researchers and a strong, diversified basic research and technology base, we are optimistic that APL will continue to receive significant federal research development grant and contract funds. In FFY 94, 63% of APL's funding was for basic research. This research remains a strength for the Laboratory.

The Laboratory's discretionary resources, derived mostly from contract fees, are approximately 3.5% of total income. The largest fraction of these funds is devoted to internal Independent Research and Development efforts, which are currently focused on new directions that build upon our Navy-related expertise. APL intends to continue to pursue opportunities with other government agencies as well as with industry. Our intent is twofold. First, we want to ensure that the Navy's considerable investment in APL continues to be applied to national technical needs. Second, during this period of military reduction and restructuring, we seek to preserve our ability to respond effectively to present and future Navy needs. We expect the Navy to remain our principal sponsor.

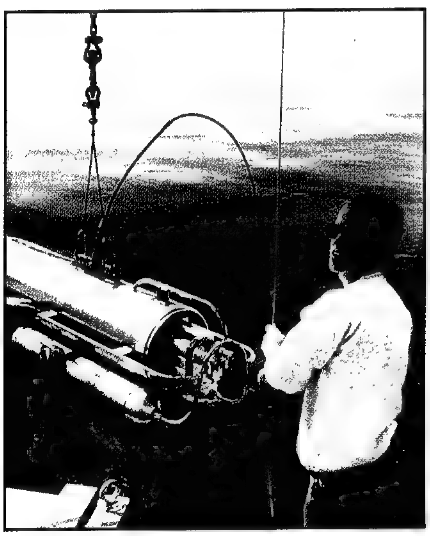
Other APL discretionary expenditures include graduate student support, staff fellowships, building improvements, and general use equipment.

APL's Department of Defense grant and contract funding exceeds that of all other units of the University combined. The Laboratory's research budget is the second largest on campus.

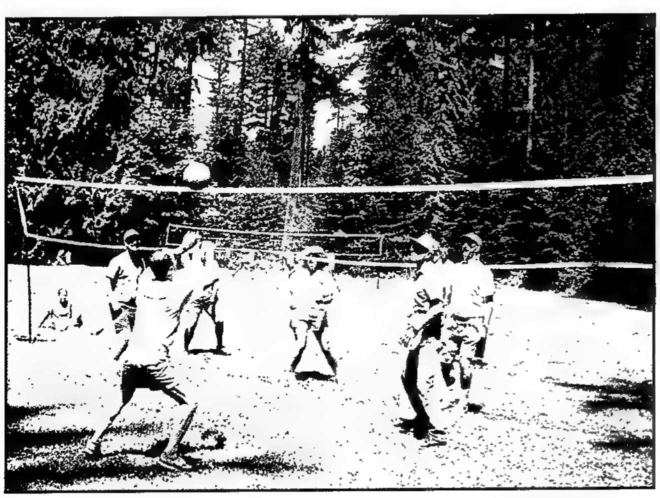
Sponsor	FFY 1993	FFY 1994
Office of the Chief of Naval Research	$9,279,214	$9,111,906
Naval Sea Systems Command	3,438,436	854,100
Naval Research Laboratory	835,300	740,128
Naval Oceanographic Office	740,000	234,900
Naval Intelligence Center	815,000	3,240,000
Naval Undersea Warfare Center	2,305,624	375,407
Naval Surface Warfare Center	5,698,710	969,683
Other Navy	2,672,806	3,243,098
Advanced Research Projects Agency	5,586,914	3,029,887
National Science Foundation	1,169,740	1,860,367
National Aeronautics & Space Administration	1,605,641	1,365,594
National Institutes of Health	206,785	456,710
National Oceanic & Atmospheric Administration	1,230,305	449,514
Other Non-Navy	779,779	373,843
Total Funding	**$36,364,254**	**$26,305,137**



APL's 50th anniversary celebration: Director Robert Spindel, Senator Slade Gorton, RADM Walter Cantrell, UW President William Gerberding, and UW College of Ocean and Fishery Sciences Dean G. Ross Heath.



Jim Turner, oceanography graduate student working with Michael Gregg, received a National Defense Science and Engineering Graduate Fellowship.



Volleyball at the APL picnic.

1993

The Laboratory was pleased to welcome several visitors during the year. • U.S. Senator Slade Gorton visited in April for a familiarization tour. • Rear Admiral Walter Cantrell, Commander Space and Naval Warfare Systems Command, participated in APL's 50th anniversary celebration. • Rear Admiral Geoffrey Chesbrough, Oceanographer of the Navy, toured the Laboratory in July. • Rear Admiral Marc Pelaez, Chief of Naval Research, visited to learn about APL's research capabilities. • John Kammerer, Navy Science Advisor to Commander Surface Forces Pacific, was briefed on programs of interest to the Surface Navy. • Jim Broyles, Navy Science Assistance Program Human Factors Representative, learned about our research programs in CD-ROM-based databases. • Rear Admiral Scott Sears, Commander Naval Undersea Warfare Center, and Captain Dennis Gibbs, Commanding Officer, Naval Undersea Warfare Center Division Keyport, were briefed on programs of interest to their commands.

Several staff and students were recognized for their achievements. • Bill Plant received the IEEE Ocean Engineering Society Distinguished Technical Achievement Award for his work in microwave remote sensing. • Fred Karig was honored by the American Defense Preparedness Association (ADPA) Undersea Warfare Division with a Bronze Medal for the critical role he has played in supporting many Navy ice camps. • Ron Roy was elected a Fellow of the Acoustical Society of America. • Kevin Fink, an Electrical Engineering graduate student working with Ed Belcher, was the recipient of the ADPA Undersea Warfare Division Fellowship.

Bob Spindel began a two-year term as President of the Marine Technology Society. • Ed Gough moved to Gaeta, Italy, where he reported to Commander Sixth Fleet for a two-year stint as the Command Science Advisor. • Don Percival, with colleague Andrew Walden of Imperial College, London, published a book entitled *Spectral Analysis for Physical Applications: Multitaper and Conventional Univariate Techniques* (Cambridge University Press). Work on a second book is under way.

In a ceremony attended by the Vice Provost and representatives of the UW Technology Transfer Office, twenty-seven APL scientists and engineers received cash awards from the Laboratory for disclosure of innovative ideas and concepts. The honorees included Azmi Al-Kurd, Jim Luby, Greg Anderson, Colin Sandwith, Kevin Williams, Ted Ellis, Elbert Pence, Paul Ingalls, Ed Belcher, Ed Gough, Skip Kolve, Dan Stearns, Bob Ruedisueli, Bill Corrin, Bob Johnson, Michael Harrington, Bill Jump, Brad Bell, Jim Mercer, Darrell Jackson, George Dworski, Pierre Mourad, Tom Sanford, Jim Carlson, Don Percival, Keith Kerr, and Bob Goddard.

1994

During 1994, the Laboratory hosted several visitors. • Members of the Naval Research Advisory Committee's Panel on Littoral Warfare/Amphibious Warfare, chaired by APL's Professor Robert Porter, met at the Laboratory during February. • Captain Alan Beam from ARPA's Marine Systems Technology Office visited to gain an understanding of APL's capabilities. • Mr. Edward Zdankiewicz, Deputy Assistant Secretary of the Navy (Mine and Undersea Warfare), toured APL during April. • Dr. David Vendittis, head of the Naval Surface Warfare Center's NSSN Signatures Directorate, was briefed on supporting programs at APL. • Members of the Technical Coordinating Group (Subgroup Nine) met at APL during October to exchange information on current research programs and requirements supporting mine warfare. • Ms. Pam Norick, Administrative Aide to Senator Patty Murray, toured the Laboratory during December.

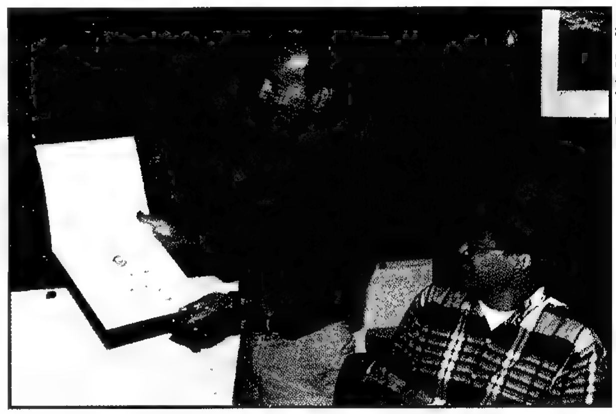
Professor Jacques Frohly of the University of Valenciennes and the Institute of Electronics and Microelectronics, Lille, France, spent the late spring at APL working with Larry Crum and Ron Roy on sonochemistry and sonoluminescence research. • Dr. Alexander Voronovich, on leave from the P.P. Shirsov Institute of Oceanology in Moscow, visited APL in March to work with Eric Thorsos. Colin Sandwith hosted Dr. Ing Fikry Asaad, an expert in water chemistry and corrosion from the National Institute of Oceanography and Fisheries, Alexandria, Egypt.

APL staff honored for their achievements included Bob Miyamoto, who received the College of Ocean and Fishery Sciences Distinguished Service Award for his activities in support of the National Neurofibromatosis Foundation, including a term as president of the Washington State Chapter. • Larry Crum was elected vice president of the Acoustical Society of America. • Bill Plant received a College of Ocean and Fishery Sciences Research Faculty Fellowship to support an extended visit to the Max Planck Institut für Meteorologie and the University of Hamburg. • Ron Stein, Tim Wen, and Fred Karig were commended by Arctic Submarine Laboratory Officer-in-Charge Captain Bruce Scott for their role in supporting Ice Camp Crystal. • Bob Drever was commended by Rear Admiral Walter Cantrell, Commander Space and Naval Warfare Systems Command, for his support of Operation Dawn. • Graduate student Kevin Fink received the ADPA Fellowship for a second year. • Stephanie McNally and Paul Dixon, undergraduate students in the Ocean Physics Department, received ONR Fellowships. • APL Technology Awards were made to Larry Crum, Bob Johnson, Elbert Pence, and Ron Roy.

APL employees past and present mourned the loss of APL's founding Director, Professor Joseph E. Henderson, on May 23, and longtime Assistant Director Joseph J. O'Rourke, on December 11.

Patricia Hardisty

Deputy Assistant Secretary of the Navy (Mine and Undersea Warfare) Edward Zdankiewicz, Director Robert Spindel, and Department Head John Hart.



Patricia Hardisty

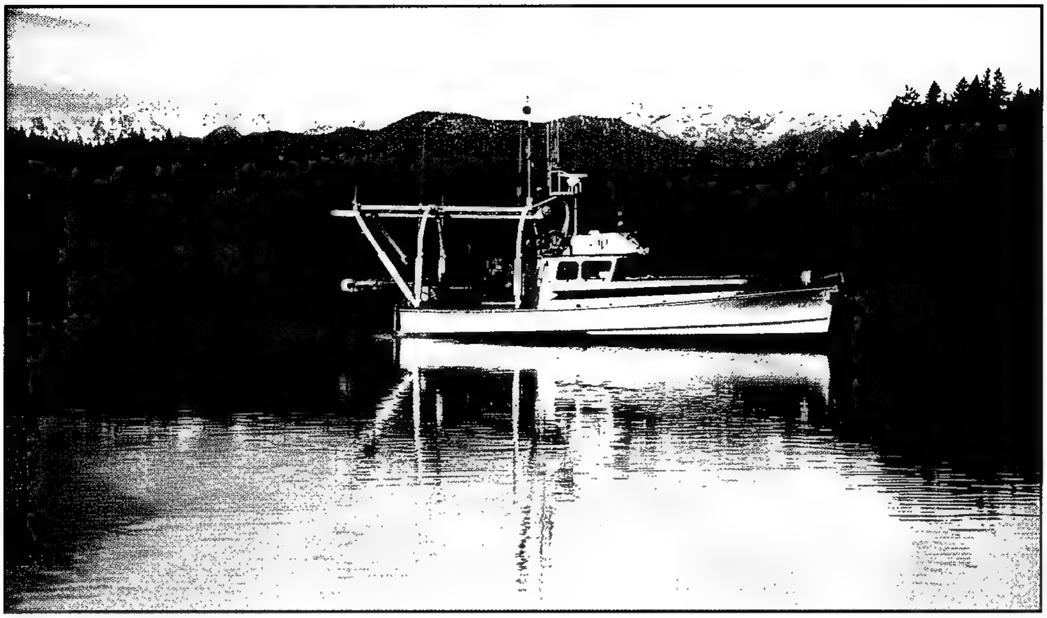
Bob Miyamoto receives the College of Ocean and Fishery Sciences' Distinguished Service Award.

Patricia Hardisty

Director's Awards during 1994 recognized Susan Womack of APL Purchasing for outstanding customer service, Pierre Mourad for establishing and administering the highly successful APL Seminar Series, and Sue Huney for exceptional service to APL in general and the Polar Science Center in particular.

Field Operations

Location	Program	Activity	Leader	Date
Off Pt. Sur	ATOC	Lay acoustic source cable	Howe	Jan '93
Equatorial Pacific	TOGA/COARE	Microstructure profiling	Gregg/Sanford	Jan–Feb '93
Georgia Strait (BC)	FRONTS	Ocean boundary layer & low-frequency acoustic scattering measurements	D'Asaro/Ewart	Feb '93
Beaufort Sea	ICEX 93	APLIS tracking range operations	Karig	Mar–Apr '93
Greenland Sea	Fram Strait Flux	Deploy & recover moorings	Aagaard	Mar–Aug '93
Lincoln Sea	Iceshelf	Test autonomous line-dispensing vehicle	Hart	Apr '93
Baltic Sea	Benthic Boundary Experiment	Mines & bottom measurements	Jackson/Williams	Apr '93
Puget Sound	SWIMS	Study of density currents	Gregg/Miller	May '93
Greenland Sea	Sea Ice/Ocean Convection	Recover moorings	Aagaard	May–Jun '93
Gulf of Mexico	Benthic Boundary Experiment	Mines & bottom measurements	Jackson	Aug '93
Arctic Ocean	Arctic Sub. Cruise	Climate & environmental studies	Colony/Morison	Aug–Sep '93
Beaufort Sea/ Chukchi Sea	Arctic Ocean Monitoring	Hydrography/deploy & recover moorings	Aagaard	Aug–Sep '93
Chukchi Sea	Western Arctic Monitoring	Hydrography/deploy & recover moorings	Aagaard	Sep '93
Beaufort Sea	Sea Ice Mechanics	Planning & logistics	Heiberg	Sep–Dec '93
Off Oregon Coast	Blimp/Microwave–Infrared Measurements	Ocean surface measurements	Plant/Jessup	Oct '93
Jervis Inlet	ATOC	Test acoustic sources	Watson	Oct '93
Off Kauai	ATOC	Lay acoustic source cable	Olson	Nov '93
San Clemente Island	FORACS	Recover & deploy targets	Mercer	Nov '93
West Coast Shelf	CABEX	Measure shallow-water propagation	Ewart	Nov–Dec '93
Jervis Inlet	ATOC	Test acoustic sources	Watson	Jan '94
Coos Head, Pacific Beach, Whidbey Island, Ford Island	ATOC	Install receivers	Mercer	Jan–Feb '94
Off Kauai	ATOC	Repair cable	Olson	Feb '94
St. Croix	FORACS	Recover & deploy targets	Mercer	Feb '94
Beaufort Sea	ICEX 93	APLIS tracking range operations	Karig	Mar–Apr '94
Beaufort Sea	Sea Ice Mechanics	Planning & logistics	Heiberg	Mar–Apr '94
Alaska	Ice Mechanics	Collect under-ice backscattering data	Ewart	Mar–Apr '94
Lincoln Sea	Iceshelf	Deploy autonomous line-dispensing vehicle	Hart	Apr '94
San Diego	Marine Boundary Layer	Test MMP on R/V *FLIP*	Gregg/Miller	Apr '94



Michael Gregg

R/V Miller *at Port Ludlow.*

Location	Program	Activity	Leader	Date
Lincoln Sea	Radionuclide Risk	Hydrography/deploy moorings	Aagaard	Apr '94
Off Pt. Sur	ATOC	Install receiver	Mercer	May '94
Off Oregon & California coasts	Blimp/Microwave Measurements	Ocean surface measurements	Plant/Jessup	Jun '94
Greenland Sea	Fram Strait Flux	Deploy & recover moorings	Aagaard	Jul–Aug '94
Weddell Sea	ANZFLUX	ACTV horizontal profiles of temperature & salinity	Morison	Jul–Aug '94
Lake Union	Acoustic Lens	Test 750-kHz model	Belcher	Jul–Aug '94
Arctic Ocean	Arctic Ocean Section	Hydrography	Aagaard	Jul–Sep '94
Hawaii	FORACS	Recover & deploy targets	Mercer	Aug '94
Ford Island	ATOC	Remove receiver	Mercer	Aug '94
San Nicholas Island	ATOC	Install receiver	Mercer	Sep '94
Bosphorus Strait	Entrainment in Density Currents	Study flow & mixing	Gregg/Miller	Sep '94
Chukchi Sea	Western Arctic Monitoring	Hydrography/deploy & recover moorings	Aagaard	Sep–Oct '94
AUTEC	FORACS	Test GPS	Ryan	Oct '94
Adak	ATOC	Install GPS	Reddaway	Oct '94
Whidbey Island	ATOC	Install additional receiver	Mercer	Oct '94
Off San Diego	ATOC	Acoustic engineering test	Howe	Nov '94
Lake Union	Acoustic Lens	Test 3-MHz model	Belcher	Nov–Dec '94

Personnel

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John C. Harlett • Deputy Director & Coordinator of Basic Research
Charles G. Sienkiewicz • Asst. Director, Applied Research & Technology

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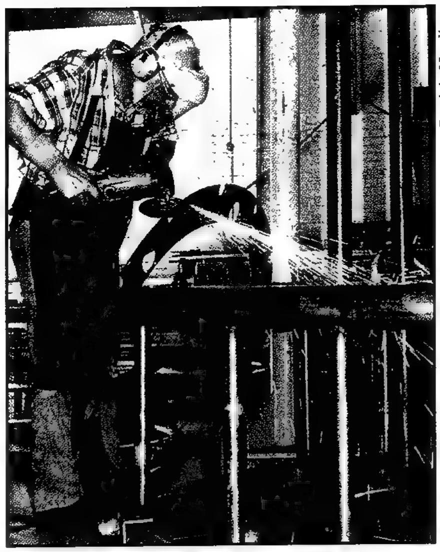
Ren-Chieh Lien • Postdoctoral Scientist-Intern

Eric D'Asaro

Mike Ohmart with the Deep Lagrangian Float.



Patricia Hardisty

Leo McGinnis at work in the APL Machine Shop.

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T. James Osse • Engineer
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Stephanie Coulter • Senior Engineer
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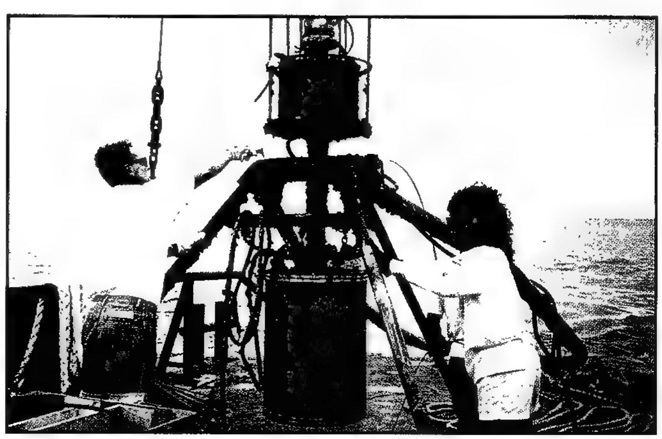
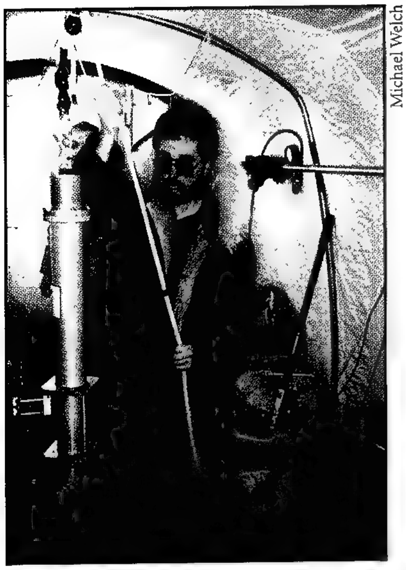
C. Matt Treiber • Student Helper
Robert E. Van Note • Senior Field Engineer



H. Bill Lewis

Jim Mercer and Shirley Weslander repair a FORACS array at sea.



Russ Light in the Arctic with the launch mechanism for SEASHUTTLE.

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Chris W. May • Engineer
Elbert A. Pence, Jr. • Principal Physicist; Senior Fellow

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Jacqueline M. Jauhola • Administrative Assistant
Dian L. Petersen • Secretary Senior
James E. Pilon • Office Assistant
Carole R. Underhill • Program Coordinator
Mary J. Watson • Student Helper

Administrative & Technical Services

RESOURCE DEPARTMENT

Gordon K. Glass • General Manager; Physical, Technical, & Central Support Resources

Building Services

Jimmy Fahey • Manager
Paul A. Aguilar • Research Aide
Chris L. Craig • Maintenance Mechanic
Jeff A. Wasierski • Maintenance Custodian

Distributed Computing Services

Eleanor M. Zitek • Manager
Walter H. Jamison • Computer Support Analyst
Charles J. Klement • Student Helper
Philip A. Torre • Student Helper

Drafting Shop

Robert W. Quimby • Field Engineer

Electronics Shop

Carl J. Larson, Jr. • Electronics Technician Supervisor
Ronald G. Gamble • Electronics Technician
Brian P. Kelly • Field Engineer
Larry C. Swan • Electronics Technician

Library

Jane M. Doggett • Library Specialist Supervisor
Sara M. Clark • Student Helper
Priscilla T. Schneider • Library Specialist

Machine Shop

Robert L. Prong • Technical Services Supervisor
Theodore B. Ellis • Instrument Maker
Bruce D. Engelfried • Order Service Coordinator
John P. Gutensohn • Instrument Maker
Manfred E. Hoffmann • Instrument Maker
Timothy W. Jansen • Instrument Maker
Milford T. Knutson • Instrument Maker
Leo P. McGinnis • Instrument Maker Lead
Richard B. Siegrist • Instrument Maker
Richard W. Syverson • Maintenance Mechanic

Marine Department

Eric S. Boget • Marine Supervisor; Field Engineer
Carl J. Larson, Jr. • Operator
Richard B. Siegrist • Operator
Daniel A. Stearns • Operator

Publications

Nancy L. Penrose • Manager
Meridyth S.T. Burnett • Editor–Research Publications
Lisa A. Haugen • Office Assistant
Dorothy F. Lowell • Graphics Designer/ Illustrator Lead
Agnes A. Sieger • Editor–Research Publications
Paul A. Zibton • Electronic Drafter

Purchasing & Property Control

Peggy K. Buschmann • Manager
Leena Amaraweera • Fiscal Technician
Thomas A. Kerrigan • Fiscal Technician
Krista-Lyn Morrison • Fiscal Technician
Jon M. Pelto • Student Helper
Susan L. Womack • Fiscal Technician

Security, Safety & Central Services

Kelley P. Knickerbocker • Manager
Cathy L. Allen • Office Assistant
Charlotte A. Boynton • Program Coordinator
Craig C. Conant • Office Assistant

Shipping & Receiving

Michael G. Miller • Warehouse Supervisor

Travel

Faye L. Harman • Fiscal Specialist

BUSINESS ADMINISTRATION DEPARTMENT

William T. Bakamis • General Manager, Business & External Affairs

Administration

Jackie S. McDonnell • Assistant to the Director

Financial Management

Anne L. Clark • Manager
Mariano B. Ballera, Jr. • Fiscal Technician
Gail M. Gilliland • Accountant
Donna J. Kasemeier • Fiscal Technician
Anthony J. Nice • Senior Accountant
May K. Shing • Principal Accountant
Larry C. West • Software Engineer

Grant & Contract Administration

Moira G. McCrory • Administrator

Human Resources/Personnel

Robert M. Bratager • Manager
Linda M. Marsh • Program Support Supervisor

— Personnel as of June 1995

In Memoriam

Joseph E. Henderson
1901–1994

Joseph J. O'Rourke
1927–1994

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